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ENGINEERING EVALUATIONS AND STUDIES

ANNUAL FINAL REPORT FOR KU-BAND STUDIES

CONTRACT NAS 9-16067, EXHIBIT A

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1.0 EXECUTIVE SUMMARY

1.1 Introduction

Axiomatix was tasked by NASA/JSC under Contract NAS 9-16067, Exhibit A, to investigate specified problem areas and concerns with respect to the Hughes Aircraft Company (HAC) Ku-band radar/communications system hardware. This final report presents results of the first 13 months of effort under this contract. The purposes of this effort were to provide fast-response evaluation and analysis of Ku-band areas of difficulty as well as to provide or suggest solutions, where appropriate. This effort is related to those Exhibit B tasks concerned with system performance aspects of the Ku-band hardware and those Exhibit C tasks concerning the Ku-band/payload interfaces.

1.2 Contents of the Final Report

Section 2 of this report is an introduction which describes the contents of this report in greater detail and summarizes the conclusions and recommendations reached by Axiomatix. Section 3 discusses the communications track problem caused by the excessive signal dynamic range at the servo input. Actual performance of the communications track servo over the hypothesized wide dynamic range of error signals is not yet known; however, initial estimates indicated that there will be a tracking problem if the dynamic range is indeed as large as anticipated.

Section 4 discusses the management/handover logic and presents a simplified description of the logic function. The HAC "truth tables" which describe the transmitter enable logic are shown to be equivalent to a single, rather simple, logic equation. This result makes it much easier to relate the effects of Ku-band commands on the transmitter status.

In Section 5, we discuss our concern with a specific component used in the SPA return-link channel 3 mid-bit detector. This component, a Motorola voltage-controlled oscillator chip, may have excessive output noise which could degrade the return link.

In Section 6, we evaluate the DA and the EA-2 Critical Design Review (CDR) data. Section 6.2 is devoted to the DA and section 6.3 is devoted to the EA-2. The SPA and EA-1 CDR data were evaluated in a prior report [1]. In both cases, the test data was evaluated by comparing the data with the acceptance criteria listed in the appropriate test procedure. Results of the evaluation are presented in tabular form and untested items from the test procedure are flagged. Appendix A is included as part of section 6.2. This appendix is a copy of an Axiomatix memorandum to NASA/JSC which documents our position that the DA ATP is not adequate to demonstrate conformance to the Rockwell Rev. B specification.

In Section 7, we analyze the effects of α/β cross-coupling on the stability and communications tracking performance of the Ku-band servo. An expression for the mean-square phase jitter of the angular error is derived as a measure of servo performance.

Finally, in Section 8, we discuss the results of a series of meetings at HAC to review the DA ATP. Rockwell had submitted 123 comments concerning the ATP which were discussed and dispositioned at the meetings. Appendix B is a list of the Rockwell comments and Appendix C gives the disposition of the Rockwell comments.

1.3 Conclusions and Recommendations

1.3.1 Communications Tracking Performance

Fixes to the DA and EA-1 required to provide adequate communications tracking capability may take as long as eight months to implement. This excessive time, plus the probable cost, dictate an alternate solution. Axiomatix has evaluated TDRSS specifications and concluded that incident flux density specification relief will permit the Ku-band system to autotrack without major LRU modifications. This analysis will be discussed in detail in the system portion of this contract's final report, Exhibit B.

1.3.2 Management Handover Logic

The cumbersome description of the transmitter enable logic in HAC documentation has been reduced to a simple logic equation. The result is that, with A side selected and communications on, the transmitter is enabled if any one of the following conditions is true:

(1) The system is in a nontracking mode (GPCDES or MANUAL)

(2) "Primary" acquisition mode is selected (wide-beam horn)

(3) Modulation control is nonautomatic, e.g., ON or OFF

(4) There is a signal present on the forward link.

1.3.3 SPA Mid-Bit Detector Frequency Stability

Based on our experience with the VCO used in the mid-bit detector, as well as manufacturers' literature, Axiomatix concludes that great care must be exercised when this device is used. Circuit layout and power supply stability are critical. The frequency stability/noise of the HAC mid-bit detector 2X clock should be measured to provide assurance that channel 3 data is not compromised by a noisy clock.

1.3.4 Critical Design Review Test Data Evaluation

Axiomatix has highlighted areas of testing oversights for both the DA and EA-2. A recurrent theme during the test data evaluation is the lack of correlation between the ATP's and the Rockwell specification.

1.3.5 Cross-Coupling Effects on Antenna Servo Stability

An analytical expression is derived which relates the mean-square phase jitter, as a measure of tracking performance, to the servo noise bandwidth, damping factor and cross-coupling gain. A necessary, but insufficient, condition for servo stability is derived: the product of cross-coupling gains must be less than unity.

1.3.6 Axiomatix Coverage of the DA ATP Reviews

Axiomatix feels that this series of meetings provided an excellent start in the attempt to correlate the DA ATP with the Rockwell specification.

2.0 INTRODUCTION

This report describes Axiomatix efforts on Ku-band problem resolution, Exhibit A of NASA/JSC Contract NAS 9-16067, entitled "Engineering Evaluations and Studies." The report period covers the first 13 months of the contract from May 1, 1980 to May 31, 1981.

2.1 Objectives

This contract provides Axiomatix an instrument with which to assist NASA/JSC with rapid-response capability to evaluate and solve unanticipated Ku-band problems. In lieu of a set of preordained tasks, Axiomatix reacts to solve problems as they occur.

2.2 General Approach

In order to keep abreast of current problems and Ku-band status, Axiomatix personnel have attended all regularly scheduled reviews, numerous special meetings called to discuss specific topics and problem areas, and participated in weekly conference calls. Specific times and places of these events are documented in the Axiomatix monthly reports submitted under this contract. Axiomatix has also obtained appropriate HAC documentation, when available, to assist in the evaluation of Ku-band development progress. This documentation consists of various HAC reports, memoranda, handouts and test data.

Where deficiencies have been found, modifications and improvements to the Ku-band system have been suggested.

2.3 Relationship to Other Tasks

The work described in this report represents an extension of prior Axiomatix work under NASA/JSC contracts as well as an adjunct to Exhibits B and C of this contract. Test data from the EA-2 and DA Critical Design Reviews (CDR) were originally intended to be covered in a prior final report under NASA/JSC contract NAS 9-15795. However, the CDR's were delayed and the test data was evaluated under this contract. Since this is an on-going contract, Axiomatix will continue to follow the progress of the Ku-band system and provide expertise as required.

2.4 Contents of this Annual Final Report

Areas of concern include hardware performance and implementation, and CDR test data evaluation. Specific topics covered are the communications tracking problem, mechanization of the management/handover logic, hardware concerns in the SPA mid-bit detector, evaluation of the DA and EA-2 test data, Block III servo performance, and a discussion of the DA ATP review meetings.

Axiomatix has investigated the communication tracking problem which is caused by wide dynamic range inputs to the tracking servo. This wide dynamic range stems from the input flux density variation, unit-to-unit variation, thermal effects, and the poor AGC performance of the track channel in the Ku-band system. The antenna servo cannot accommodate the wide dynamic range postulated. HAC has proposed a series of fixes to the DA and/or EA-1 which, with varying degrees of flux density specification relief, could provide the required tracking performance. Axiomatix has reviewed the proposed fixes and, in Section 3, we discuss the nature of the problem in more detail as well as the implications of implementing a hardware change to provide adequate performance.

In Section 4, we discuss the management/handover logic. Specifically, we evaluate the functional dependence of the transmitter enable signal on the controlling variables and commands. A minor documentation discrepancy in the HAC SPA specification has been discovered. HAC has been alerted and, after review with Rockwell, agreement was reached to accept the SPA with the transmitter enable logic as implemented.

In Section 5, we discuss our concern with the frequency stability of the mid-bit detector at the SPA high-data rate digital input port. The concern is that noise in the mid-bit circuit may affect the return link quality. Axiomatix experience with similar circuits used to generate a two-times clock, phase locked to the high-data rate clock, indicate excessive noise at the VCO output which, in turn, clocks out the encoded channel 3 data. Characteristics of this circuit and a possible alternative are described in this section.

Axiomatix attended the DA and EA-1 CDR's during this reporting period. Test data presented at the CDR's has been evaluated by Axiomatix and the results of this evaluation are presented in Section 6. The DA test data is covered in section 6.2 and the EA-2 is covered in section 6.3. The DA test data evaluation is presented in tabular form and the test data is compared with the applicable ATP paragraphs. ATP paragraphs which are not verified during testing are flagged, and a summary table of unverified items is included. For the EA-2, a verification matrix is given which correlates the Rockwell specification with the HAC ATP. Additionally, a series of tables is given which correlate the parameters being measured and the radar modes. Again, a summary table is presented which lists the untested specification paragraphs.

Block III servo performance is still a matter of concern. In Section 7, we describe Axiomatix efforts to date to characterize the angle-tracking loop, with emphasis on stability and tracking performance with α/β cross-coupling. A necessary, but insufficient, criterion for stability is derived which is independent of the order of the tracking loop, and an expression for the mean-square phase jitter of the antenna as a function of the servo noise bandwidth and damping factor is derived.

Axiomatix personnel attended a series of review meetings to discuss the DA ATP in which an attempt was made to correlate the ATP with the Rockwell requirements. In Section 8, we discuss the results of these meetings. Appendices B and C are adjuncts to this section; Appendix B shows a list of Rockwell comments presented at the meeting and Appendix C describes the disposition of the comments.

2.4.1 Issues Not Covered in Major Sections

During this contract, Axiomatix was asked by NASA/JSC to provide expertise to help solve problems on an immediate basis. The results of these efforts sometimes did not warrant a formal report, and could easily be covered with a brief telephone call or informal memorandum. These issues are not covered in this report. One topic not covered is Axiomatix attendance at the Deliverable System Test Equipment (DSTE) seminar at HAC in July 1980. The seminar was attended so that Axiomatix could easily become familiar with the hardware/software in the event NASA needed assistance with the DSTE. The seminar was useful in giving potential DSTE users an overview; however, it could have been compressed to about one-half the time. While the seminar was a start, Axiomatix feels that the only effective method to gain familiarity with the DSTE will be by "hands-on" experience.

2.5 Conclusions and Recommendations

2.5.1 Communications Tracking Performance

Fixes to the DA and EA-1 required to provide adequate communications tracking capability may take as long as eight months to implement. This excessive time, plus the probable cost, dictate an alternate solution. Axiomatix has evaluated TDRSS specifications and concluded that incident flux density specification relief will permit the Ku-band system to autotrack without major LRU modifications. This analysis will be discussed in detail in the system portion of this contract's final report, Exhibit B.

2.5.2 Management Handover Logic

The cumbersome description of the transmitter enable logic in HAC documentation has been reduced to a simple logic equation. The result is that, with the A side selected and communications on, the transmitter is enabled if any one of the following conditions is true:

(1) The system is in a nontracking mode (GPCDES or MANUAL)

(2) "Primary" acquisition mode is selected (wide-beam horn)

(3) Modulation control is nonautomatic, e.g., ON or OFF

(4) A signal is present on the forward link.

2.5.3 SPA Mid-Bit Detector Frequency Stability

Based on our experience with the VCO used in the mid-bit detector, as well as manufacturers' literature, Axiomatix concludes that great care must be exercised when this device is used. Circuit layout and power supply stability are critical. The frequency stability/noise of the HAC mid-bit detector two-times clock should be measured to provide assurance that channel 3 data is not compromised by a noisy clock.

2.5.4 Critical Design Review Test Data Evaluation

Axiomatix has highlighted areas of testing oversights for both the DA and EA-2. A recurrent theme during the test data evaluation is the lack of correlation between the ATP's and the Rockwell specification. Appendix A of this report is a copy of an Axiomatix memorandum to NASA/JSC which documents our position that the DA ATP is inadequate to demonstrate conformance to the Rockwell specification.

2.5.5 Cross-Coupling Effects on Antenna Servo Stability

An analytical expression is derived which relates the mean-square phase jitter, as a measure of tracking performance, to the servo noise bandwidth, damping factor and cross-coupling gain. A necessary, but insufficient, condition for servo stability is derived: the product of cross-coupling gains must be less than unity. The expression for phase jitter is currently being evaluated in terms of the Ku-band rate stabilization loop parameters.

2.5.6 Axiomatix Coverage of the DA ATP Reviews

Axiomatix feels that this series of meetings provided an excellent start in the attempt to correlate the DA ATP with the Rockwell specification.

3.0 COMMUNICATIONS TRACKING PERFORMANCE

3.1 Introduction

The Ku-band communications system employs monopulse steering to closed-loop angle-track the TDRS forward link signal. The communications tracking system consists of a four-element difference channel feed and a sum feed on the high-gain dish, a monopulse comparator, and RF down-conversion and tracking electronics in the EA-1 LRU. HAC has analyzed the angle-track subsystem performance as it is currently implemented and has concluded that this subsystem cannot tolerate the wide variation in received signal strength of the Rockwell specification.

In this section, we describe the implications of trying to resolve this problem with hardware changes via resolution with specification changes. In the final report of Exhibit B of this contract, we will describe a solution based solely on specification relief.

In addition to the dynamic range problem, some crosstalk has been measured between the α and β channels. In Section 7 of this report, we analyze the servo-tracking degradation due to noise cross-coupling as well as self-coupling, both with and without crosstalk.

3.2 Ku-Band Dynamic Range Limitations

The genesis of the dynamic range problem lies in the stringent tracking requirements during severe Orbiter motion with a wide dynamic range signal. In addition, the Ku-band autotrack subsystem has several deficiences which contribute to the problem. One of the more significant degradations is due to the AGC envelope suppression at low SNR levels. At negative C/N (dB) into the AGC, the output-to-input power ratio is 2:1. Unfortunately, the negative C/N region is within the expected operating range of the AGC circuit. The cumulative effect of signal strength variation, thermal and unit variation, and AGC envelope suppression results is a detector output/servo input variation of 39 dB. This result is from data presented by HAC during a splinter session on March 17, 1981. Figure 1 depicts the communications-tracking system and degradations at the various points. Some DA losses, or degradations, have a compound effect in that they influence both the signal amplitude into the detector as well as the percentage AM versus angle at the detector input.

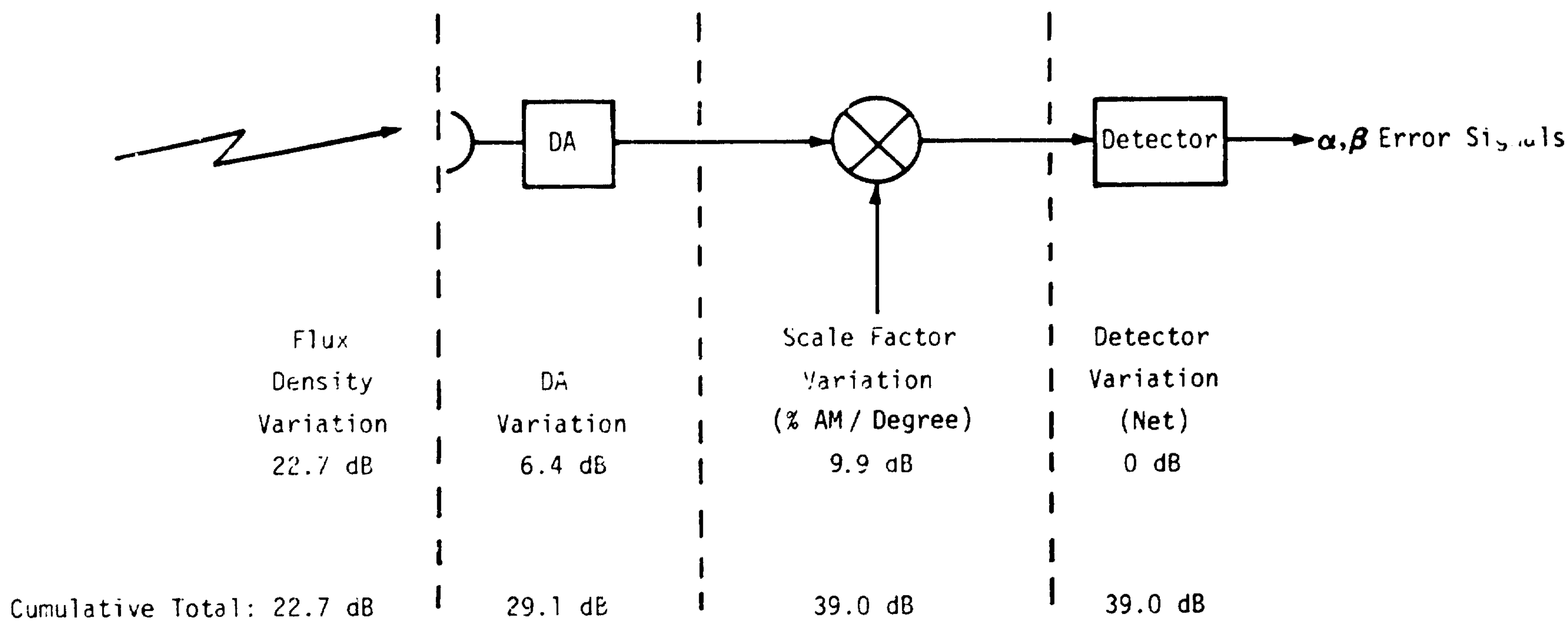

Figure 1. Communications System Tracking Degradations
(Based on HAC-supplied data, March 1981)

3.3 Conclusions

The effect of the 39 dB dynamic range at the servo input is not explicitly known at this time; however, it is safe to assume that the servo is not remotely capable of accommodating this range. HAC has partitioned the dynamic range problem between the servo and the systems preceding the servo: an assumption is made that the servo can accommodate a dynamic range of 15 dB and various "fixes" have been proposed to bring the detector output/servo input dynamic range down to 15 dB. Most fixes entail a combination of EA-1 and DA modifications plus flux density specification relief. Unfortunately, the proposed modifications which provide adequate performance gain require an estimated eight months to be implemented. Axiomatix has conclcuded that the schedule impact of hardware fixes is not acceptable, and significant specification relief will be required to accommodate the existing hardware, as will be discussed in the Exhibit B report.

4.0 MANAGEMENT HANDOVER LOGIC SIMPLIFICATION

4.1 Introduction

In this section, we discuss aspects of the management/handover logic which concern transmitter enable logic. Discussions of this logic in [2] and [3] are rather difficult to follow, particularly since the function of the logic is intertwined with A-side/B-side selection. Our understanding of the functional dependence of transmitter enable on the controlling variables (e.g., tracking mode, acquisition mode, modulation control and signal present) is facilitated by considering the A-side only. The series of "truth tables" in [3] can be replaced by one simple logic equation. Alternatively, the process can be described simply by noting that, with communications on, the only configuration that disables the transmitter consists of being in a tracking mode with the high-gain antenna selected for acquisition, no signal present on the forward link, and in automatic modulation control. All other conditions with communications on enable the transmitter. In the following section, we derive these results based on information from [2] and [3].

4.2 Derivation of Simplified Transmit Enable Logic

The logic equation which defines the transmit enable state is derived below. From Table 3.2.1.4-11 of [3], transmit enable logic is defined in terms of three intermediate variables; this table is shown below.

HANDOVER LOGIC	0	1	1	1	1
OVER RIDE LOGIC	Ø	1	X	X	X
ACQUISITION LOGIC	Ø	Ø	0	1	X
TRANSMIT ENABLE	0	1	0	1	1

The X's represent a third logic state. In order to define the output in terms of Orbiter and Ku-band inputs, the tri-state logic can be defined in terms of additional auxiliary variables, as shown below.

Let OVER RIDE LOGIC = 0 be defined as

ORL = 0, ORLX = 0

Let OVER RIDE LOGIC = 1 be defined as

ORL = 1, ORLX = 1

Let OVER RIDE LOGIC = X be defined as

ORL = 0, ORLX = 1.

Similarly, we can define two auxiliary variables for ACQUISITION LOGIC, AL and ALX. A new transmit enable table is shown below.

HL	0	0	0	0	1	1	1	1	1
ORL	0	0	1	1	1	1	0	0	0
ORLX	0	0	1	1	1	1	1	1	1
AL	0	1	0	1	0	1	0	1	0
ALX	0	1	0	1	0	1	0	1	1
TE	0	0	0	0	1	1	0	1	1

TE represents TRANSMIT ENABLE and HL represents HANDOVER LOGIC.

From the above table, we see that $TE = HL\cdot(ORL\cdot ORLX+\overline{ORL}\cdot ORLX\cdot ALX)$. The first of the intermediate variables, HL, is defined in Table 3.2.1.4-8 of [3] and is shown below with the names of the variables compressed to permit a more compact notation. Only the A side commands are given.

HANDOVER LOGIC

A SIDE COMMANDS	COMMON	0	1	1	1	1	1	1	1	1	1
	TDRSEAST	Ø	Ø	Ø	Ø	1	0	1	1	0	0
	TDRSWEST	Ø	Ø	Ø	Ø	Ø	1	0	0	1	1
	ENCODEMODE2	Ø	Ø	0	Ø	1	1	1	1	1	1
	SELECTA	Ø	Ø	Ø	Ø	Ø	Ø	1	0	1	0

TRANSMITTER A (HL)	0	1	1	1	1	1	1	0	1	0

From the previous table,

$$\overline{HL} = \overline{COMMON} + COMMON \cdot ENCODEDMODE2 \cdot \overline{SELECTA}.$$

However, A side is always selected; hence, $\overline{SELECTA} = 0$ and HL = COMMON.

The second two intermediate variables, ORL and ORLX, are derived from Table 3.2.4-9 (sic) of [3], as shown below.

MODULATION CONTROL 1	1	0	Ø	Ø
MODULATION CONTROL 2	1	1	0	0
SIGNAL PRESENT	Ø	Ø	0	1
OVER RIDE LOGIC	1	1	X	1

This table is modified to define the auxiliary variables

MODCON1	1	0	Ø	Ø
MODCON2	1	1	0	0
SIGPRES	Ø	Ø	0	1
ORL	1	1	0	1
ORLX	1	1	1	1

Thus, ORL = MODCON2 + SIGPRES and ORLX = 1.

The acquisition logic is given in development specification Table 3.2.1.4-10, shown below.

ENCODED MODE 1	1	0	0	0
SIGNAL PRESENT	Ø	1	0	0
PRIMARY ACQ MODE ON/OFF	Ø	Ø	0	1
ACQUISITION LOGIC	X	X	1	0

Thus, the final two auxiliary variables are defined below in the modified table.

ENCMOD1	1	0	0	0
SIGPRES	Ø	1	0	0
PRIACQOFF	Ø	Ø	0	1
AL	0	0	1	0
ALX	1	1	1	0

From the above table, AL = $\overline{ENCMOD1}\cdot\overline{SIGPRES}\cdot\overline{PRIACQOFF}$, and ALX = ENCMOD1 + SIGPRES + $\overline{PRIACQOFF}$.

The defining equation of the transmit enable logic was shown to be TE = $HL\cdot(ORL\cdot ORLX+\overline{ORL}\cdot ORLX\cdot ALX)$. Since ORLX = 1, this reduces to TE = $HL\cdot(ORL+\overline{ORL}\cdot ALX)$. This is logically equivalent to TE = $HL\cdot(ORL+ALX)$, as can be shown using a Karnaugh map, trial and error, or whatever.

The next step is to substitute the independent variables for the intermediate variables, which gives:

TE = $COMMON\cdot(MODCON2+SIGPRES+ENCMOD1+\overline{PRIACQOFF})$.

The modulation control bits MODCON1 and MODCON2 are defined as follows:

MODCON1	MODCON2	MODULATION MODE
0	0	AUTO
0	1	OFF
1	1	ON
1	0	AUTO

These two bits provide the logic to unconditionally turn the modulation on or off or enable modulation in the presence of a forward link signal only (AUTO).

SIGPRES should be self-explanatory, e.g., SIGPRES = 1 if a forward link signal is detected.

The encoded mode bits are defined as follows from information given at the SPA CDR:

ENCMOD1	ENCMOD2	STEERING MODE
0	0	AUTO
0	1	GPCACQ
1	0	MANUAL
1	1	GPCDES

PRIACQOFF = 1 when in alternate acquisition mode, e.g., when using the high gain antenna. Thus, $\overline{\text{PRIACQOFF}}$ = 1 in primary (wide-beam horn) mode. Returning to the defining equation, the transmitter is enabled with COMMON = 1 and any one or more of the variables MODCON2, SIGPRES, ENCMOD1 or $\overline{\text{PRIACQOFF}}$ = 1. From the defining tables, MODCON2 = 1 in a nonautomatic mode, e.g., OFF or ON, and ENCMOD = 1 in any nontracking mode, MANUAL or GPCDES.

Thus, the transmitter is enabled if the communications-on bit is one and any one of the following conditions is true:

(1) The system is in a nontracking mode (GPCDES or MANUAL)
(2) "Primary" acquisition mode is selected (wide-beam horn)
(3) Modulation control is nonautomatic, e.g., ON or OFF
(4) A signal is present on the forward link.

Condition (3) is at variance with Paragraph 3.2.3.1.5 of [3], which states that, in the alternate acquisition mode, the transmitter is inhibited except when modulation is commanded on. The transmitter will be enabled if the modulation control switch is in either the OFF or ON position, regardless of acquisition mode. This is not a serious problem, and Rockwell has agreed to accept the logic as is.

5.0 SPA MID-BIT DETECTOR FREQUENCY STABILITY

5.1 Introduction

The SPA has an adaptive threshold mid-bit detector at the channel 3 mode 1 input port. This port accepts high-rate data and clock at the rate of 2 - 50 Mbps, positions a sampling clock at the data mid-bit, and rate one-half convolutionally encodes the sampled data stream. The sample clock is derived from a two-times clock which, in turn, is locked to the input clock. The two-times clock is a voltage-controlled oscillator based on a Motorola MC1658. Axiomatix has experienced problems with this chip generating considerable noise and has supplanted it with an MC1648. Our concern, discussed in the next section, is that this noise could be added to the return link.

5.2 Mid-Bit Detector VCO Noise

The design of a phase-lock-loop with a VCO output covering the 4 - 100 MHz range presents some problems. Not many VCO's operate over a 25:1 frequency range. In this regard, the use of an RC-type of oscillator, where the frequency varies inversely with the value of capacity, is advantageous. An LC oscillator will vary its frequency inversely as the square root of the value of capacity.

The price paid for the greater frequency deviation available from an RC oscillator is the lack of a tuned circuit which will reduce noise sidebands around the operating frequency. The point about VCO noise is graphically illustrated by curves published by Motorola. In addition to the MC1658, which is an RC-type oscillator manufactured by Motorola, they make the MC1648. This device uses an LC-tuned circuit to determine the operating frequency.

Figure 2, which is taken from Motorola's MECL Integrated Circuit Data Book, shows an RMS noise frequency deviation of less than 60 Hz and an operating frequency of 100 MHz for an MC1648. Figure 3 is the comparable curve for the MC1658, and it was taken from the same source. It shows an RMS noise frequency deviation of 5000 Hz at an operating frequency of less than 70 MHz. It also shows a sharp increase in slope, starting at about 40 MHz, so the noise at an operating frequency of 100 MHz may be very high.

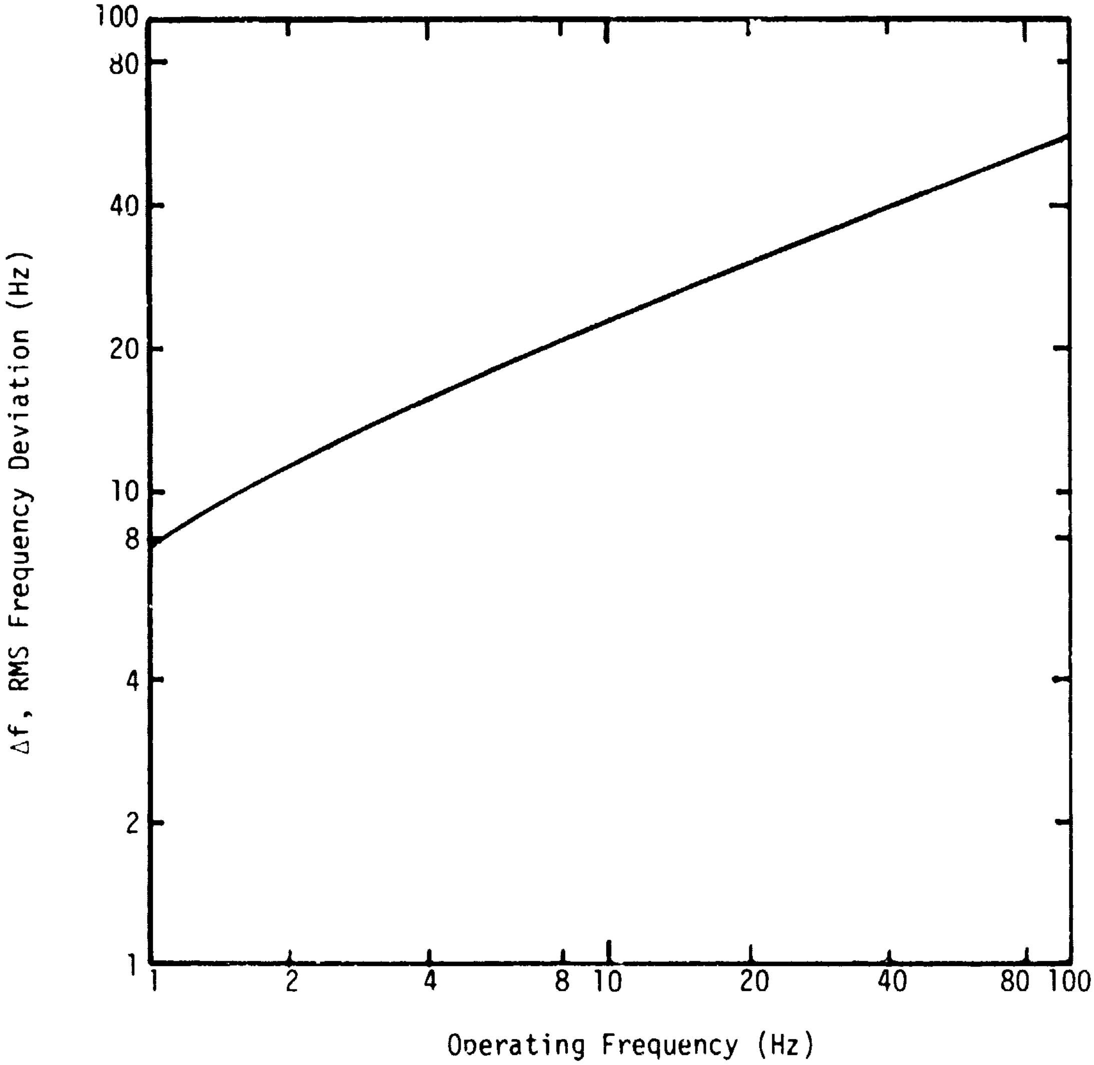

Figure 2. RMS Noise Deviation versus Frequency, Motorola MC1648

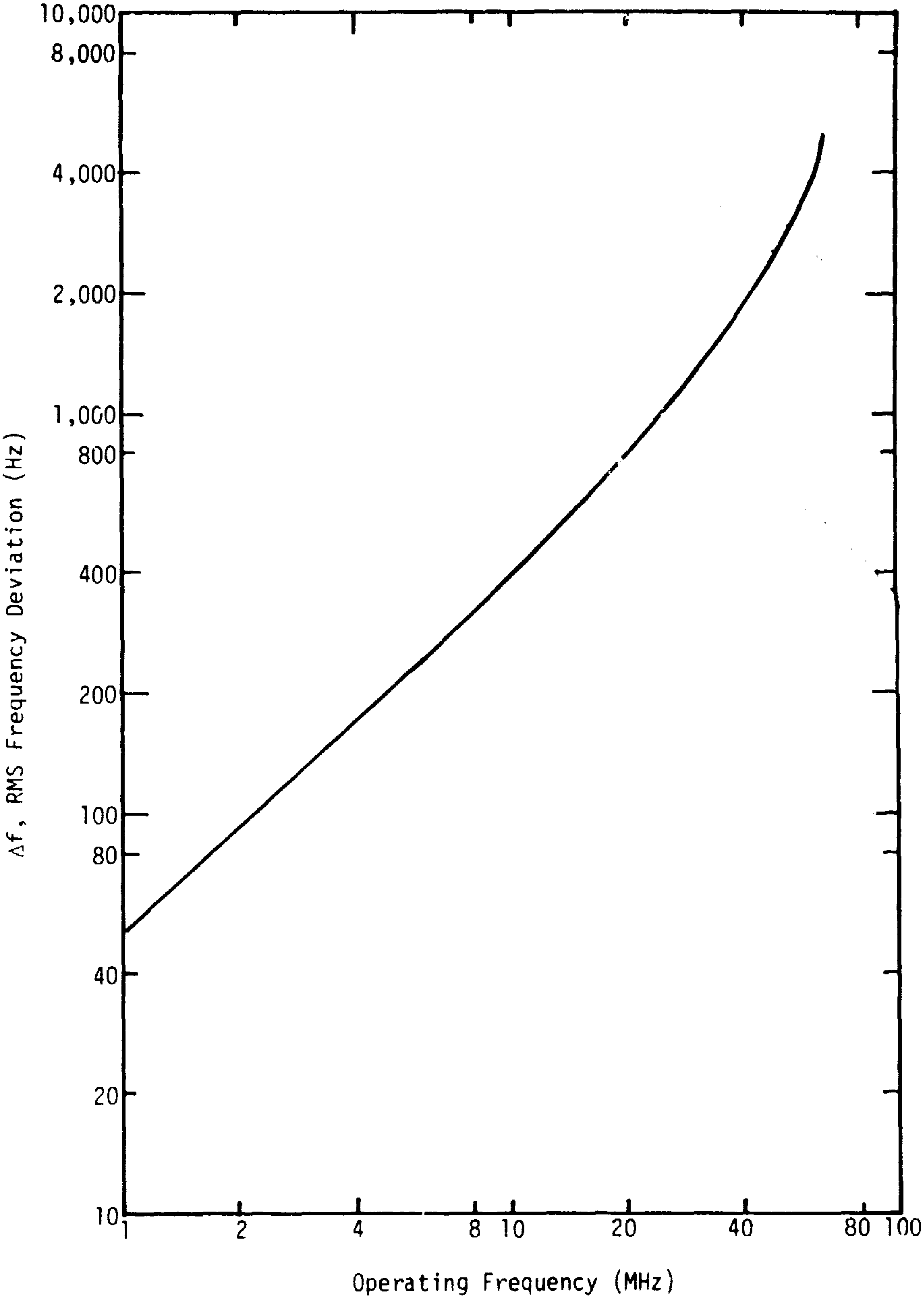

Figure 3. RMS Noise Deviation versus Frequency, Motorola MC1658

The problem introduced into a phase-lock-loop by VCO noise is that the only way to reduce the noise is to build a wide bandwidth loop in order to suppress the noise produced by the VCO. The wide bandwidth loop is not capable of smoothing the carrier input which it is tracking. Therefore, a compromise in loop bandwidth will probably be required to provide reasonable smoothing of the input signal tracked, and extreme measures may be necessary to reduce VCO noise. These measures, in addition to very careful filtering of power supplies, interface signals, layout, etc., might include custom selection of the MC1658's for optimum noise characteristics.

5.3 Recommendations

The current HAC test procedures do not include a clock noise measurement. Since this noise could affect the return link signal, the noise characteristics of the derived clock should be measured to determine the input on the return link signal.

6.0 CRITICAL DESIGN REVIEW TEST DATA EVALUATION

6.1 Introduction

In this section, we evaluate the CDR test data. Section 6.2 covers the ADL and ESTL DA LRU test data, and section 6.3 describes the ADL EA-2 test data.

6.2 ADL and ESTL DA LRU CDR Test Data

This section covers the ADL and ESTL DA LRU CDR test data presented by Hughes Aircraft Company (HAC) on May 27-28, 1980, and the ESTL DA acceptance test data compiled by HAC during December 1980. Both ADL and ESTL DA LRU CDR test data are contained in HAC Report #HS237-2665, and the ESTL DA LRU acceptance data data are contained in HAC Report #HS318-0161, dated December 4, 1980. All three sets of DA test data were compiled using HAC Procedure #TS32012-042, Rev. A, "Ku-Band Acceptance and Qualification Test Specification."

6.2.1 DA Findings

Axiomatix has reviewed more than 538 pages of HAC DA test data by comparing the data with the acceptance criteria listed in the test procedure. Tables 1 - 3 compare the three sets of test data with the applicable ATP paragraphs and indicates whether or not the specific ATP paragraphs were verified during testing. By reviewing Table 4, it is noted that a number of items were unverified for the ADL DA, such as no α/β lobing tests, no power monitor tests and no monopulse phase verification. It is further noted that the ESTL CDR tests also involved a number of unverified items, such as no α/β lobing tests and no self-tests.

Table 4 summarizes those tests listed in the ATP which were not performed on either the ADL or ESTL DA LRU's. Notice that the ESTL DA was more thoroughly tested per the ATP at the LRU level.

In reviewing the test data as indicated in Tables 1-3, a number of tests were not performed due to hardware problems and, in some cases, the tests produced results which were out of specification. We feel that it is not necessary to restate all the ADL and ESTL DA performance problems discovered during the tests simply because Rockwell, NASA, Hughes and Axiomatix are well aware of the problems. For example, it is

Table 1. DA ATP versus DA LRU Tests (ADL/CDR)

HUGHES DA ACCEPTANCE AND QUALIFICATION TEST PROCEDURE TS32012-042		
Paragraph	Title or Subsections	ADL DA (CDR Test Data)
3.2.3.1.2	Inspection	Verified
3.2.3.1.5	Continuity	Anomalies: J1-C to J1-D, 11K S/B open J1-D to J1-E, 11K S/B open J1-G to J1-H, 45b S/B open J1-A to J1-B not measured J2-A to J2-F, 53.1Ω, S/B ~ 80Ω J4-41 to J4-60, 1.8Ω S/B open J4-41 to J4-63, 1.8Ω S/B open J4-1 to J4-2, open; S/B ~ 110Ω J4-4 to J4-5, open; S/B ~ 110Ω
3.2.3.1.6	Coax cable insertion loss	Not measured
3.2.3.2	Leak (DEA pressure)	Not measured
3.2.3.3	Gimbal assembly functions	N/A (note: following gimbal tests conducted at V_{BUS} = +28 VDC only)
3.2.3.3.1.3	DEA +15, DEA -15 Boom stow enable II on	Not measured Not verified
3.2.3.3.1.4	Antenna lock Encoder initialization Mechanical limits Obscuration zone Motor shutoff limits	Verified Verified Verified Not verified Reference data only
3.2.3.3.1.5	Antenna deployment Boom stow enable II off	 Verified
3.2.3.3.1.6	Antenna stow Boom stow enable II on	 Verified
3.2.3.3.2	Gimbal motor torques (deleted from latest test procedure)	Verified
3.2.3.3.3	Rate sensor assembly	N/A
3.2.3.3.3.1	Gimbal drift	Data illegible

Table 1. DA ATP versus DA LRU Tests (ADL/CDR) (Cont'd)

HUGHES DA ACCEPTANCE AND QUALIFICATION TEST PROCEDURE TS32012-042		
Paragraph	Title or Subsection	ADL DA (CDR Test Data)
3.2.3.3.3.2	Gyro scale factor	Data illegible
3.2.3.3.4	Table D2 gimbal angle encoder	Verified
3.2.3.3.5	Antenna misalignment	Verified
3.2.3.3.6.1	Radar search	Not verified (reference data only)
3.2.3.3.6.3	Table D3 miniscan	Not verified (reference data only)
3.2.3.3.7	Gyro & gimbal noise	Not measured
3.2.3.3.7.2	Gimbal friction	Not measured
3.2.3.3.8	Table D5, α & β sig. gen.	Not measured
3.2.3.4	DEA functions	N/A
3.2.3.4.1.2	Motor shutoff limits	Not measured (reference data only)
3.2.3.4.1.4	Coax insertion loss	Not measured
3.2.3.4.2	Radar mode power-up sequence	N/A
3.2.3.4.2.1	DEA bus current/LVPS fault off	Verified
3.2.3.4.2.2	DMA narrowbeam	Not measured
3.2.3.4.2.4	Operate status	Verified
3.2.3.4.2.5	Disable transmit enable	Not measured
3.2.3.4.2.6	Transmit enable (30° deploy)	Verified
3.2.3.4.2.7	Transmit off	Not measured
3.2.3.4.2.8	DEA off	Not measured
3.2.3.4.2.9	DEA on	Not measured
3.2.3.4.3	Radar mode frequencies	Verified
3.2.3.4.4	RF power (radar mode)	Verified except for RF power monitor
3.2.3.4.6	Comm. power-up sequence	Verified except that filament timeout not measured
3.2.3.4.8	Radar mode transmit time delay	TWT bypass mode not verified (polaroids illegible)

Table 1. DA ATP versus DA LRU Tests (ADL/CDR) (Cont'd)

HUGHES DA ACCEPTANCE AND QUALIFICATION TEST PROCEDURE TS32012-042		
Paragraph	Title or Subsection	ADL DA (CDR Test Data)
3.2.3.4.9	Radar Mode Channel Change Time	Verified except that 1 - 4 is 154 μs, but S/B < 100 μs
3.2.3.4.10	Comm. Mode -- Widebeam	Verified except that power monitor not measured (polaroids illegible)
3.2.3.4.11	Comm. Mode -- Narrowbeam	Verified except that power monitor not measured (polaroids illegible)
3.2.3.4.12.2	Self-test -- α	Not measured
3.2.3.4.12.3	Transmitter off	Verified
3.2.3.4.12.4	α-track IF amp. and phase	Not measured
3.2.3.4.12.5	α-track tests (Cont'd)	Not measured
3.2.3.4.12.6	Self-test--β/β track track IF	Not measured
3.2.3.4.12.8	β-track tests (Cont'd)	Not measured
3.2.3.4.12.10	Comm. mode first LO sample	Verified
3.2.3.4.13	Radar input bandwidth & gain	N/A
3.2.3.4.13.3	Radar diff. input passband	Verified (polaroid print data cards illegible)
3.2.3.4.13.4	Comm. diff. input passband	Amplitude not verified (polaroid print data cards illegible)
3.2.3.4.13.5	Radar second IF (10 MHz BW)	Verified (polaroid print data cards illegible)
3.2.3.4.13.6	Radar/comm sum input passband	Verified (polaroid print data cards illegible)
3.2.3.4.13.7	Data IF	Verified (polaroid print data cards illegible)
3.2.3.4.14	AGC	Verified
3.2.3.4.15.2	Radar sum-signal rejection	Verified
3.2.3.4.15.3	Image frequency	Verified
3.2.3.4.15.4	Spur rejection--track IF	Verified
3.2.3.4.15.5	Comm. sum signal rejection	Verified
3.2.3.4.15.6	Radar spur rejection	Verified

Table 1. DA ATP versus DA LRU Tests (ADL/CDR) (Cont'd)

HUGHES DA ACCEPTANCE AND QUALIFICATION TEST PROCEDURE TS32012-042		
Paragraph	Title or Subsection	ADL DA (CDR Test Data)
3.2.3.4.15.11	Main bang leakage	Verified
3.2.3.4.15.12	TWT bypass--10 MHz bandwidth	Not verified
3.2.3.4.15.13	High power--3 MHz bandwidth	Verified
3.2.3.4.16.1	Enable sum channel	Not verified
3.2.3.4.16.2	Sum long pulse	Verified
3.2.3.4.16.3	Diff. long pulse	Verified
3.2.4	Monopulse phase verification	Not verified

Table 2. DA ATP versus DA LRU Tests (ESTL/CDR)

HUGHES DA ACCEPTANCE AND QUALIFICATION TEST PROCEDURE TS32012-042		
Paragraph	Title or Subsections	ESTL DA (CDR Test Data)
3.2.3.1.2	Inspection	Verified
3.2.3.1.5	Continuity	Anomolies: CP12-S to CP12-T, 71.1K S/B ~ 11K CP12-W to CP12-X, 22.7K S/B ~ 40K CP12-P to CP12-R, 6.86K S/B ~ 450Ω CP12-G to CP12-H, 50 S/B ~ 80Ω CP40B-P to CP40B-R, 118Ω S/B ~ 110Ω
3.2.3.1.6	Coax cable insertion loss	Not measured
3.2.3.2	Leak (DEA pressure)	Not measured
3.2.3.3.1.3	Gimbal assembly functions	N/A (Note: following gimbal tests conducted at V_{BUS} = +28 VDC only)
3.2.3.3.1.4	DEA +15, DEA -15 Boom stow enable II on	OK Verified
3.2.3.3.1.4	Antenna lock Encoder initialization Mechanical limits Obscuration zone Motor shutoff limits	Not verified Verified Not verified Not verified Reference data only
3.2.3.3.1.5	Antenna deployment Boom stow enable II off	 Verified
3.2.3.3.1.6	Antenna stow Boom stow enable II on	 Verified
3.2.3.3.2	Gimbal motor torques (Deleted from latest test procedure	Verified
3.2.3.3.3	Rate sensor assembly	N/A
3.2.3.3.3.1	Gimbal drift	Measured, but no pass/fail criteria listed
3.2.3.3.3.2	Gyro scale factor	Verified
3.2.3.3.4	Table D2 gimbal angle encoder	Verified

Table 2. DA ATP versus DA LRU Tests (ESTL/CDR) (Cont'd)

HUGHES DA ACCEPTANCE AND QUALIFICATION TEST PROCEDURE 1S32012-042		
Paragraph	Title or Subsections	ESTL DA (CDR Test Data)
3.2.3.3.5	Antenna misalignment	Verified
3.2.3.3.6.1	Radar search	Verified (reference data only)
3.2.3.3.6.3	Table D3 miniscan	Verified (reference data only)
3.2.3.3.7	Gyro and gimbal noise	Verified
3.2.3.3.7.2	Gimbal friction	Not measured
3.2.3.3.8	Table D5, α & β sig. gen.	Verified
3.2.3.4	DEA functions	N/A
3.2.3.4.1.2	Motor shutoff limits	Verified
3.2.3.4.1.4	Coax insertion loss	Verified
3.2.3.4.2	Radar mode power-up sequence	N/A
3.2.3.4.2.1	DEA bus current/LVPS fault off	Verified
3.2.3.4.2.2	DMA narrowbeam	Verified
3.2.3.4.2.4	Operate status	Verified
3.2.3.4.2.5	Disable transmit enable	Verified
3.2.3.4.2.6	Transmit enable (30° deploy)	Verified
3.2.3.4.2.7	Transmit off	Verified
3.2.3.4.2.8	DEA off	Not measured
3.2.3.4.2.9	DEA on	Not measured
3.2.3.4.3	Radar mode frequencies	Verified
3.2.3.4.4	RF power (radar mode)	Medium & low RF power outputs below specification
3.2.3.4.6	Comm. power-up sequence	Verified except that filament timeout 10 seconds too long
3.2.3.4.8	Radar mode transmit time delay	Verified (polaroid print data cards illegible)
3.2.3.4.9	Radar mode channel change time	Verified

Table 2. DA ATP versus DA LRU Tests (ESTL/CDR) (Cont'd)

HUGHES DA ACCEPTANCE AND QUALIFICATION TEST PROCEDURE TS32012-042		
Paragraph	Title or Subsections	ESTL DA (CDR Test Data)
3.2.3.4.10	Comm. mode--widebeam	Verified except RF power output below specification by 1.39 dBm (polaroid illegible)
3.2.3.4.11	Comm. mode--narrowbeam	Verified (polaroid print data card illegible)
3.2.3.4.12.2	Self-test--α	Verified
3.2.3.4.12.3	Transmitter off	Verified
3.2.3.4.12.4	α-track IF amp. and phase	Not measured (α-track nonoperative)
3.2.3.4.12.5	α-track tests (cont'd)	Not measured (α-track nonoperative)
3.2.3.4.12.6	Self-test--β/β track track IF	Not measured except for β lobing current (β-track nonoperational)
3.2.3.4.12.8	β-track tests (cont'd)	Not meausred (β-track nonoperative)
3.2.3.4.12.10	Comm. mode first LO sample	Verified
3.2.3.4.13	Radar input bandwidth & gain	N/A
3.2.3.4.13.3	Radar diff. input passband	Verified (polaroid print data cards illegible)
3.2.3.4.13.4	Comm. diff. input passband	Verified (polaroid print data card illegible)
3.2.3.4.13.5	Radar second IF (10 MHz BW)	Verified (polaroid print data cards illegible)
3.2.3.4.13.6	Radar/Comm sum input passband	Verified (polaroid print data cards illegible)
3.2.3.4.13.7	Data IF	Verified (polaroid print data card illegible
3.2.3.4.14	AGC	Verified
3.2.3.4.15.2	Radar sum-signal rejection	Verified
3.2.3.4.15.3	Image frequency	Verified
3.2.3.4.15.4	Spur rejection--track IF	Verified
3.2.3.4.15.5	Comm. sum signal rejection	Verified
3.2.3.4.15.6	Radar spur rejection	Verified
3.2.3.4.15.11	Main bang leakage	Verified

Table 2. DA ATP versus DA LRU Tests (ESTL/CDR) (Cont'd)

HUGHES DA ACCEPTANCE AND QUALIFICATION TEST PROCEDURE TS32012-042		
Paragraph	Title or Subsections	ESTL DA (CDR Test Data)
3.2.3.4.15.12	TWT bypass--10 MHz bandwidth	Verified
3.2.3.4.15.13	Hi-h power--3 MHz bandwidth	Verified (polariod print data card illegible)
3.2.3.4.16.1	Enable sum channel	Not verified
3.2.3.4.16.2	Sum long pulse	Verified (polaroid print data cards illegible)
3.2.3.4.16.3	Diff long pulse	Verified (polaroid print data cards illegible)
3.2.4	Monopulse phase verification	Not verified

Table 3. DA ATP versus DA LRU Tests (ESTL/ATP)

HUGHES DA ACCEPTANCE AND QUALIFICATION TEST PROCEDURE TS32012-042		
Paragraph	Title or Subsections	ESTL DA (ATP Test Data)
3.2.3.1.2	Inspection	Verified
3.2.3.1.5	Continuity	Verified
3.2.3.1.6	Coax cable insertion loss	Not measured
3.2.3.2	Leak (DEA pressure)	Out of specification
3.2.3.3	Gimbal assembly functions	N/A (Note: Following gimbal tests conducted at V_{BUS} = +28 VDC only)
3.2.3.3.1.3	DEA +15, DEA -15 Boom stow enable II on	OK Verified
3.2.3.3.1.4	Antenna lock Encoder initialization Mechanical limits Obscuration zone Motor shutoff limits	Deleted Deleted Deleted Deleted Reference data only
3.2.3.3.1.5	Antenna Deployment Boom stow enable II off	 Verified
3.2.3.3.1.6	Antenna stow Boom stow enable II on	 Verified
3.2.3.3.2	Gimbal motor torques (Deleted from latest test procedure)	Deleted
3.2.3.3.3	Rate sensor assembly	N/A
3.2.3.3.3.1	Gimbal drift	Verified
3.2.3.3.3.2	Gyro scale factor	Verified
3.2.3.3.4	Table D2 gimbal angle encoder	Verified, but criteria is less than ±3 counts and some points were -3
3.2.3.3.5	Antenna misalignment	Verified
3.2.3.3.6.1	Radar search	Not measured (reference data only)

Table 3. DA ATP versus DA LRU Tests (ESTL/ATP) (Cont'd)

HUGHES DA ACCEPTANCE AND QUALIFICATION TEST PROCEDURE TS32012-042		
Paragraph	Title or Subsections	ESTL DA (ATP Test Data)
3.2.3.3.6.3	Table D3 miniscan	Verified (reference data only)
3.2.3.3.7	Gyro and gimbal noise	Deleted
3.2.3.3.7.2	Gimbal friction	Verified
3.2.3.3.8	Table D5, α & β sig. gen.	Verified
3.2.3.4	DEA functions	N/A
3.2.3.4.1.2	Motor shutoff limits	Not measured (reference data only)
3.2.3.4.1.4	Coax insertion loss	Verified
3.2.3.4.2	Radar mode power-up sequence	N/A
3.2.3.4.2.1	DEA bus current/LVPS fault off	Verified (filament timeout out of specification)
3.2.3.4.2.2	DMA narrowbeam	Verified
3.2.3.4.2.4	Operate status	Verified
3.2.3.4.2.5	Disable transmit enable	Verified
3.2.3.4.2.6	Transmit enable (30° deploy)	Verified
3.2.3.4.2.7	Transmit off	Verified
3.2.3.4.2.8	DEA off	Out of specification
3.2.3.4.2.9	DEA on	Verified
3.2.3.4.3	Radar mode frequencies	Verified
3.2.3.4.4	RF power (radar mode)	Verified except low RF power output out of spec by 0.18 dB
3.2.3.4.6	Comm. power-up sequence	Verified except filament timeout out of spec by 2 seconds
3.2.3.4.8	Radar mode transmit time delay	Verified
3.2.3.4.9	Radar mode channel change time	Verified
3.2.3.4.10	Comm. mode--widebeam	Verified
3.2.3.4.11	Comm. mode--narrowbeam	verified
^.3.4.12.2	Self-test--α	Verified

Table 3. DA ATP versus DA LRU Tests (ESTL/ATP) (Cont'd)

HUGHES DA ACCEPTANCE AND QUALIFICATION TEST PROCEDURE TS32012-042		
Paragraph	Title or Subsections	ESTL DA (ATP Test Data)
3.2.3.4.12.3	Transmitter off	Verified
3.2.3.4.12.4	α-track IF amp. and phase	Not measured
3.2.3.4.12.5	α-track tests (cont'd)	Not measured
3.2.3.4.12.6	Self-test -β/β track track IF	Not measured
3.2.3.4.12.8	β-track tests (cont'd)	Not measured
3.2.3.4.12.10	Comm. mode first LO sample	Verified
3.2.3.4.13	Radar input bandwidth & gain	N/A
3.2.3.4.13.3	Radar diff. input passband	Verified
3.2.3.4.13.4	Comm. diff. input passband	Verified
3.2.3.4.13.5	Radar second IF (10 MHz BW)	Verified
3.2.3.4.13.6	Radar/comm sum input passband	Verified
3.2.3.4.13.7	Data IF	Verified
3.2.3.4.14	AGC	Verified
3.2.3.4.15.2	Radar sum-signal rejection	Verified
3.2.3.4.15.3	Image frequency	Verified
3.2.3.4.15.4	Spur rejection--track	Verified
3.2.3.4.15.5	Comm sum signal rejection	Verified
3.2.3.4.15.6	Radar spur rejection	Verified
3.2.3.4.15.11	Main bang leakage	Verified
3.2.3.4.15.12	TWT bypass--10 MHz bandwidth	Verified
3.2.3.4.15.13	High power--3 MHz bandwidth	Verified
3.2.3.4.16.1	Enable sum channel	Verified
3.2.3.4.16.2	Sum long pulse	Verified
3.2.3.4.16.3	Diff. long pulse	Verified
3.2.4	Monopulse phase verification	Verified, but no pass/fail criteria listed.

Table 4. ADL and ESTL DA Test Summary

ADL DA (CDR Test Data)	ESTL DA (CDR Test Data)	ESTL DA (ATP Test Data)
No α/β lobing tests	No α/β lobing tests	No self-tests
No power monitor tests	No self-tests	No tests as a function of bus voltage
No self-tests	No environmental tests	
No environmental tests	No monopulse verification tests	
No scanning tests	No tests as a function of bus voltage	
No monopulse verification tests		
No tests as a function of bus voltage		

well known that: (1) there is no self-test at this time, (2) a problem exists with the RF power monitor, (3) the ADL antenna has poor performance compared to the ESTL antenna, (4) the ADL has a 4° gimbal clocking error, and (5) the monopulse phase tests were not performed on the ADL unit.

However, other problems surfaced during testing. For example, the gimbal angle encoder stability requirements are less than ±3 counts, but the ESTL ATP data has seven out of 15 angle settings where the count was either +3 or -3, which corresponds to a ±0.264° error. The requirements specify a maximum error of ±0.166°.

The initial ESTL DA CDR test data indicated that the medium and low RF power level outputs were below specification. This problem has been addressed, but when retested with the ATP, the ESTL DA still is out of specification by 0.18 dB at the low RF power level.

The ATP lists a very detailed procedure for verifying the monopulse phase, except that the ATP fails to list any accept/reject criteria. One area of concern is that no monopulse phase verification tests were conducted on the ADL DA and, since there is no accept/reject criteria listed in the ATP, one cannot draw any conclusions from the ESTL DA phase verification tests either.

A major area of concern is that the ATP was conducted at the nominal bus voltage of 28 VDC--not over the range of 24 - 32 VDC. Many LRU problems are discovered when acceptance testing is conducted as a function of bus voltage, and it is possible that all the DA problems have not yet surfaced.

The greatest area of concern deals with the ATP itself. As compared to the more than 538 pages of the HAC DA test data to the HAC ATP, the test data review has not produced any significant surprises. However, before one concludes that successfully passing the HAC DA ATP guarantees a properly functioning DA, Axiomatix will reemphasize a fundamental flaw in the HAC test program.

The Hughes DA ATP, #TS32012-042, Rev. A, was designed to verify Hughes Document #DS32012-031, "Development Specification Deployed Assembly for the Ku-Band Integrated Radar and Communications Equipment," but was not designed to verify Rockwell Specification #MC409-0025, Rev. B, "Integrated Communications and Radar Equipment, Ku-Band." Axiomatix previously commented on this situation per a memo to Jim Kelly of NASA, dated September 11, 1980, as shown in Appendix A.

The basic problem is that the Rockwell specification is the baseline document and there is a very low degree of correlation between the Hughes ATP and the Rockwell specification. Eventually, through a very tedious examination of the HAC ATP and the Rockwell requirements, some correlation would exist but, at this time, no such comparison has been performed. Table 5 gives some examples of the different requirements listed in each document and how specific ATP paragraphs address only portions of the applicable Rockwell paragraphs.

The purpose of Table 5 is to give the reader a flavor of the problems faced when comparing both documents. Ideally, if a one-to-one correspondence existed between the requirements, it would be very straightforward to determine the adequacy of the acceptance testing. As it now stands, Axiomatix can state that the ESTL DA passed most of the HAC ATP but without an exhaustive paragraph-by-paragraph comparison, it is unknown at this time whether or not the DA LRU really meets the requirements listed in the Rockwell documentation.

Both Axiomatix and Rockwell have repeatedly brought up this problem, plans have been formulated to address this situation, yet nothing has happed to change it. One of the purposes of the TM01 document that is now two years late in being issued by HAC is to address the testing program and provide a means with which to have some confidence that the hardware is meeting Rockwell requirements.

Table 5. Examples of Differences Between HAC and RI Requirements

Item	HAC ATP Paragraph HS32012-Q42	HAC-Specified Requirements DS32012-031	Rockwell Specification Paragraph MC409-0025, Rev. B	Rockwell-Specified Requirements MC409-0025, Rev. B
RF power--high	3.2.3.4.4	18 ± 3.5 dBm	30.3.2.1.2.2.3b	16.99 to 18.75 dBm
RF power--med.	3.2.3.4.4	-12 ± 3 dB from high	30.3.2.1.2.2.3b Paragraphs 30.3.2.1.2.2.3a, c-k spread throughout ATP	-12 ± 2 dB from high
Radar mode transmit-TWT bypass	3.2.3.4.8	51 ± 17 ns	30.3.1.2.4.8.1m Paragraphs 30.3.1.2.4.8.1a-ℓ spread throughout ATP	55.5 ± 12 ns
AGC dynamic range radar mode 3	3.2.3.4.14	-	-	-
• Step IF AGC Atten.	-	-30 ± 2.5 dB	30.3.2.1.2.2.5s	-30 ± 2 dB
• Transmitter Limiter AGC	-	-30 ± 1.5 dB	30.3.2.1.2.2.5r	-30 ± 1 dB
• Linear AGC-5	-	-42 ± 4 dB	30.3.2.1.2.2.5t Paragraphs 30.3.2.1.2.2.5a-q u,v spread throughout ATP	-42 ± 2 dB

6.2.2 DA Conclusions/Recommendations

As per Table 4, a number of tests were not performed for both the ADL DA and the ESTL DA. However, since the ADL unit is being used by Rockwell to verify the Shuttle interfaces only, the testing performed by HAC on the ADL DA has been adequate. Since the ESTL DA will be used primarily at the ESTL to verify link performance, again, HAC testing has been sufficient.

The major issue of correlating the HAC ATP to the RI specification still remains, however, and it is Axiomatix's position that this issue must be aggressively addressed. Without the TM01 or an equivalent document to tie the HAC ATP to the Rockwell requirements, there is no confidence that HAC is delivering properly functioning DA's. As Axiomatix has repeatedly stated, the longer this issue remains unresolved, the greater the probability that future DA's may have problems which will not be discovered until late in the Ku-band program. Axiomatix therefore recommends that either Rockwell, Hughes or Axiomatix perform the task of correlating the Hughes ATP with the Rockwell requirements, and that this task should be performed as soon as possible.

6.3 ADL EA-2 LRU Test Data

This section covers the ADL EA-2 LRU CDR test data presented by Hughes on September 25, 1980. The tests were conducted during June 1980 to a preliminary copy of HAC ATP #TP32012-076 with the test results contained in HAC Report #HS237-3031-1, dated September 29, 1980.

6.3.1 EA-2 Findings

Axiomatix has reviewed the HAC ADL EA-2 LRU CDR test data by comparing the data with the acceptance criteria listed in the ATP. For a first cut, the prerelease version of the ATP is very complete, with the functional tests divided into the following categories:

- Power
- Timing
- Detection Sensitivity
- Sidelobe Test
- Velocity Processing
- Acquisition Program
- Serial Data
- False Alarm Rate
- Automatic Gain Control
- Range Processor
- Angle Processing
- Track Program Timing

The ATP exercised all of the EA-2 functions and, for the most part, the ADL EA-2 performed within specification tolerances. However, some anomalies such as a high false alarm rate did occur. All of the out-of-specification test data are the result of EA-2 problems which were fully documented by either Axiomatix, Hughes and/or Rockwell previously. Since the EA-2 problems are known to all parties, Axiomatix feels that it is not necessary to restate them in this report.

Even though the ADL EA-2 LRU CDR test data review did not uncover any new EA-2 problems, the review has given Axiomatix an opportunity to study the EA-2 ATP in greater detail. As mentioned in the DA section, the major Axiomatix concern deals with the low degree of correlation between the Hughes DA specification and the Rockwell DA requirements. On the other hand, with the EA-2 ATP, the procedure is written in a different format than the DA ATP, and the different EA-2 format contributes to a very high degree of correlation with the Rockwell specification. Each of the EA-2 ATP functional test sections, as listed above, deals with a major requirement or a significant portion of a major requirement within the Rockwell specification, making cross-correlation much easier.

Table 6 is the Rockwell specification/Hughes EA-2 ATP verification matrix. Note that, for the most part, the Hughes ATP verifies the applicable Rockwell paragraphs.

Tables 7-10 are also matrices of the three radar operating phases (search, acquisition and track) versus designated ranges, and each table indicates in which mode (GPC acquisition, GPC designate, autotrack and manual) and target type (active and passive) given parameters, such as timing synchronization signals, are measured and verified. The active modes and the passive autotrack and passive manual modes are not shown as a function of designated range because range designates are not used in these radar modes. By studying Tables 7-10, it is noted that a fairly comprehensive number of tests are being conducted.

On the other hand, Table 11 is the summary of untested Rockwell specification paragraphs. The first two items listed in Table 11 require verification of the interface signals only, and item 3 cannot be addressed until Rockwell defines the GPC designate, passive mode, operation. The last four items in Table 11 are testing oversights which must be addressed since verification is required per the Rockwell ATP requirements.

Table 6. EA-2 LRU

Rockwell Specification MC 409-0025, Rev B		Req'd per Table 40-IX Acceptance Tests	N/A	Hughes Acceptance Test Procedure TP 32012-076
Paragraph Number	Paragraph Title			Paragraph Number
40	Electronic Assembly EA-2		X	
40.1	Scope		X	
40.2	Applicable Documents		X	
40.3	Requirements		X	
40.3.1	Item Definition		X	
40.3.1.1	Item Diagram		X	
40.3.1.2	Interface Definition		X	
40.3.1.2.1	Electrical Power		X	
40.3.1.2.2	Mechanical		X	
40.3.1.2.2.1	Connector Location and Pin Alignment		X	
40.3.1.2.3	Cooling		X	
40.3.1.2.4	Signal Interface Definition		X	
40.3.1.2.4.1	EA-1A Interface		X	
40.3.1.2.4.1.1	Serial Digital I/O Characteristics	X		Signals supplied by test equipment; therefore, EA-2 implicitly tested.
40.3.1.2.4.1.1.1	EA-2A Serial Input Data Characteristics	X		
40.3.1.2.4.1.1.2	EA-2A Clock Characteristics	X		
40.3.1.2.4.1.1.3	EA-2A Data Cover Pulse Characteristics	X		
40.3.1.2.4.1.1.4	EA-2A Status Cover Pulse Characteristics	X		

Table 6. EA-2 LRU (Cont'd)

Rockwell Specification MC 409-0025, Rev B		Req'd per Table 40-1 Acceptance Tests	N/A	Hughes Acceptance Test Procedure TP 32012-076
Paragraph Number	Paragraph Title			Paragraph Number
40.3.1.2.4.1.2	Controls and Status Discretes		X	
Input: a.	Radar On	X		2.2.1
b.	Radar Standby		X	
c.	Radar Power Low	X		2.7.15
d.	Radar Power Medium	X		2.7.15
Output: a.	Target Present	X		2.12
b.	Lobing Enable	X		Not verified
c.	Lobing Alpha/Beta	X		Not verified
d.	Lobing Phase 0 - 180°	X		Not verified
40.3.1.2.4.1.3	Analog Signal Characteristics		X	
40.3.1.2.4.1.3.1	Radar Signal Strength	X		2.7.12
40.3.1.2.4.1.3.2	Alpha Error/Beta Error	X		2.11
40.3.1.2.4.1.3.3	156 MHz Reference Frequency	X		Signal supplied by test equipment; therefore, EA-2 implicitly tested.
40.3.1.2.4.2	DA-A Interface		X	
40.3.1.2.4.2.1	Controls and Status Discretes		X	
a.	Radar Power Low	X		2.7.15
b.	Radar Power Medium	X		2.7.15
c.	Frequency Select A, B, C	X		2.4.2.1, 2.4.2.2, 2.4.2.3

Table 6. EA-2 LRU (Cont'd)

Rockwell Specification MC 409-0025, Rev B		Req'd per Table 401X Acceptance Tests	N/A	Hughes Acceptance Test Procedure TP 32012-076
Paragraph Number	Paragraph Title			Paragraph Number
d.	High Sample Rate Select	X		Verified throughout ATP
e.	Radar Sum Enable	X		Not verified
f.	Radar Difference Enable	X		Not verified
g.	TWT Bypass Enable	X		Verified throughout ATP
h.	Transmitter Limiter AGC	X		Not verified
i.	First IF Step AGC	X		Not verified
40.3.1.2.4.2.2	Analog Signal Characteristics		X	
40.3.1.2.4.2.2.1	Linear AGC	X		2.7
40.3.1.2.4.2.3	Timing Pulses I/O Characteristics		X	
40.3.1.2.4.2.3.1	Transmit Gate	X		2.4
40.3.1.2.4.2.3.2	Receiver Gate	X		2.4
40.3.1.2.4.2.3.3	Exciter Gate	X		2.4
40.3.1.2.4.2.4	Radar Second IF	X		Signal supplied by test equipment; therefore, EA-2 implicitly tested.
40.3.1.2.4.3	LRU Test Connector		X	
40.3.1.2.4.3.1	GSE Checkout	X		Verified by conducting ATP
40.3.1.2.4.3.2	SRU Checkout	X		Verified by conducting ATP
40.3.1.2.5	Instrumentation	X		Verified by conducting ATP
40.3.1.3	Item Identification		X	

Table 6. EA-2 LRU (Cont'd)

Rockwell Specification MC 409-0025, Rev B		Req'd per Table 40-IX Acceptance Tests	N/A	Hughes Acceptance Test Procedure TP 3?012-076
Paragraph Number	Paragraph Title			Paragraph Number
40.3.2	Characteristics		X	
40.3.2.1	Perforamnce		X	
40.3.2.1.1	Life Requirements		X	
40.3.2.1.1.1	Operating Life		X	
40.3.2.1.1.2	Useful Life		X	
40.3.2.1.1.3	Shelf Life		X	
40.3.2.1.2	Functional Performance Requirements		X	
40.3.2.1.2.1	Primary Power Consumption	X		2.2.1
40.3.2.1.2.1.1	Duty Cycle		X	
40.3.2.1.2.1.2	Stabilization		X	
40.3.2.1.2.2	Operating Modes		X	
40.3.2.1.2.3	Antenna Steering Modes		X	
40.3.2.1.2.3.1	GPC Acquisition, Passive Mode	X		2.4, 2.12, 2.13
40.3.2.1.2.3.1.1	Search Phase	X		2.4
40.3.2.1.2.3.1.2	Acquisition Phase	X		2.4, 2.12
40.3.2.1.2.3.1.3	Initial Track Phase	X		2.4, 2.13
40.3.2.1.2.3.1.4	Final Track Phase	X		2.4, 2.13
40.3.2.1.2.3.2	GPC Designate, Passive Mode (TBS)	X		Not verified

Table 6. EA-2 LRU (Cont'd)

Rockwell Specification MC 409-0025, Rev B		Req'd per Table 40-IX Acceptance Tests	N/A	Hughes Acceptance Test Procedure TP 32012-076
Paragraph Number	Paragraph Title			Paragraph Number
40.3.2.1.2.3.3	Autotrack, Passive Mode	X		2.12, 2.13, 2.4
40.3.2.1.2.3.3.1	Search Phase	X		2.4
40.3.2.1.2.3.3.2	Acquisition Phase	X		Not verified
40.3.2.1.2.3.3.3	Initial Track	X		2.13, 2.4
40.3.2.1.2.3.3.4	Final Track	X		2.13, 2.4
40.3.2.1.2.3.4	Manual, Passive Mode	X		2.4
40.3.2.1.2.3.5	GPC Acquisition, Active Mode	X		2.12, 2.13, 2.4
40.3.2.1.2.3.5.1	Search Phase	X		2.4
40.3.2.1.2.3.5.2	Acquisition Phase	X		2.12, 2.13, 2.4
40.3.2.1.2.3.5.3	Track Phase	X		2.13, 2.4
40.3.2.1.2.3.6	GPC Designate, Active Mode	X		2.12, 2.13, 2.4
40.3.2.1.2.3.7	Autotrack, Active Mode	X		2.12, 2.13, 2.4
40.3.2.1.2.3.8	Manual, Active Mode	X		2.12, 2.13, 2.4
40.3.2.1.2.4	Prob. of Detection & False Alarm Rate	X		2.5, 2.6
40.3.2.1.2.5	Parameter Measurement Accuracies	X		2.9, 2.10, 2.11
40.3.2.1.2.5.1	Parameter Meas. Accuracy Convergence Time	X		Not verified
40.3.2.1.2.5.2	Measurement Data Output Sample Rate	X		Not verified
40.3.2.1.2.6	Clutter Performance	X		Not verified

Table 6. EA-2 LRU (Cont'd)

Rockwell Specification MC 409-0025, Rev B		Req'd per Table 401X Acceptance Tests	N/A	Hughes Acceptance Test Procedure TP 32012-076
Paragraph Number	Paragraph Title			Paragraph Number
40.3.2.1.2.7	Sidelobe Detection Discrimination	X		2.8, 2.12
40.3.2.1.2.8	Automatic Gain Control	X		2.7
40.3.2.1.2.8.1	Search Gain Control	X		2.7
40.3.2.1.2.8.2	Track Gain Control	X		2.7
40.3.2.1.2.9	Received Signal Amplitude Estimation	X		2.7
40.3.2.1.2.10	Status Flag Output Command Logic	X		2.3
40.3.2.1.2.10.1	Angle Rate Data Valid	X		2.3
40.3.2.1.2.10.2	Angle Data Valid	X		2.3
40.3.2.1.2.10.3	Angle Track Enable	X		2.3
40.3.2.1.2.10.4	Generating Test Target	X		2.3
40.3.2.1.2.10.5	Operate	X		2.3
40.3.2.1.2.10.6	Range Data Valid	X		2.3
40.3.2.1.2.10.7	Range Rate Data Valid	X		2.3
40.3.2.1.2.10.8	Miniscan	X		2.3
40.3.2.1.2.10.9	Sidelobe	X		2.3
40.3.2.1.2.10.10	Track	X		2.3
40.3.2.1.2.11	Built-In Test	X		2.4
40.3.2.1.2.12	GSE Test Points (GSE Connectors)	X		Tested throughout ATP
40.3.2.1.2.13	Electrical Power Consumption	X		2.2

Table 7. Timing Synchronization Signals

Designated Ranges		Search	Acquisition	Track
nmi	ft			
> 18.9	> 114,912			
9.3 - 18.9	56,544 to 114,912	Passive GPC (¶2.4.4.2) R_D = 94,000 ft	Passive GPC (¶2.4.4.5) R_D = 94,000 ft (Partial tests)	Passive* (¶2.4.4.7) R_D = 100,000 ft
7.2 - 9.3	43.776 to 56,544			
3.8 - 7.2	23,104 to 43,776			
1.9 - 3.8	11,552 to 23,104			
0.95 - 1.9	5,776 to 11,552			
0.42 - 0.95	2,554 to 5,776	Passive GPC (¶2.4.4.1) R_D = 4,000 ft	Passive GPC (¶2.4.4.5) R_D = 4,000 ft (Partial tests)	Passive* (¶2.4.4.6) R_D = 4,000 ft
0.016 - 0.42	97 - 2,554			
		Passive Manual/Auto (¶2.4.4.3) R_T = 4,000 ft Active (¶2.4.4.4) R_T = 4,000 ft	Active (¶2.4.4.5) R_T = 4,000 ft (Partial tests)	Active (¶2.4.4.6) R_T = 4,000 ft Active (¶2.4.4.6) R_T = 1,000,000 ft

*GPC & auto mode same

R_D = Range Designate; R_T = **Range** of Target; Paragraphs refer to **Hughes** TS 32012-076 (EA-2 ATP)

Table 8. Deployed Assembly Gates

Designated Ranges		Search	Acquisition	Track
nmi	ft			
> 18.9	> 114,912	Passive GPC R_D = 128,000 ft (¶2.4.3.8)		
9.3 - 18.9	56,544 to 114,912			
7.2 - 9.3	43,776 to 56,544			Passive* R_D = 48,000 ft (¶2.4.3.16) w/pulse width override Passive* R_D = 48,000 ft (¶2.4.3.17) w/o pulse width override
3.8 - 7.2	23,104 to 43,776	Passive GPC R_D = 28,000 ft (¶2.4.3.7)		Passive* R_D = 28,000 ft (¶2.4.3.15)
1.9 - 3.8	11,552 to 23,104	Passive GPC R_D = 18,000 ft (¶2.4.3.6)		Passive* R_D = 18,000 ft (¶2.4.3.14)
0.95 - 1.9	5,776 to 11,552	Passive GPC R_D = 8,000 ft (¶2.4.3.5)		Passive* R_D = 8,000 ft (¶2.4.3.13)
0.42 - 0.95	2,554 to 5,776	Passive GPC R_D = 4,000 ft (¶2.4.3.4)		Passive* R_D = 4,000 ft (¶2.4.3.12)
0.016-0.42	97 - 2,554	Passive GPC R_D = 1,000 ft (¶2.4.3.1)		Passive* R_D = 1,000 ft (¶2.4.3.11)
		Passive Manual/Auto, short range (¶2.4.3.3) Passive Manual/Auto, long range (¶2.4.3.9)		Active* (¶2.4.3.19) R<9.3 nmi w/pulse width override R_T = 50,000 ft Active* (¶2.4.3.20) R<9.3 nmi w/o pulse width override R_T = 50,000 ft
NOTE: All tests repeated (¶2.4.3.23)		for test mode	*GPC & auto mode same	

R_D = Range Designate ; R_T = Range of Target ; Paragraphs refer to Hughes TS 32012-076 (EA-2 ATP)

Table 8. Deployed Assembly Gates (Cont'd)

Designated Ranges		Search	Acquisition	Track
nmi	ft			
		Active GPC/Manual/Auto (¶2.4.3.10)		Active* (¶2.4.3.2.1) w/o pulse width override $R > 9.3$ nmi $R_T = 88{,}000$ ft

NOTE: All tests repeated for test mode (¶2.4.3.23)

*GPC & auto mode same

R_D = Range Designate

R_T = Range of Target

Paragraphs refer to Hughes TS 32012-076 (EA-2 ATP)

Table 9. Acquisition Program Verification

Designated Ranges nmi	Designated Ranges ft	Search	Acquisition	Track
> 18.9	> 114,912			
9.3 - 18.9	56,114 to 114,912		Passive GPS Acq (¶2.12.9) R_C = 98,000 ft	
7.2 - 9.3	43,544 to 56,544			Passive* GPC (¶2.13.3) R > 7.2 nmi R_T = 50,000 ft
3.8 - 7.2	23,104 to 43,776		Passive GPC Acq (¶2.12.6) R_D = 28,000 ft	Passive* GPC (¶2.13.2) 3.8 nmi < R < 7.2 nmi R_T = 30,000 ft
1.9 - 3.8	11,552 to 23,104		Passive GPC Acq (¶2.12.3) R_D = 10,000 ft	
0.95 - 1.9	5,776 to 11,552			
0.42 - 0.95	2,554 - 5,776			Passive* GPC (¶2.13.1) R < 3.8 nmi R_T = 4,000 ft
0.016-0.042	97 - 2,554		Passive GPC Acq (¶2.12.12) R_D = 2,000 ft	
			Active GPC Acq (¶2.12.16) R > 9.5 nmi R_T = 80,000 ft Active GPC Acq (¶2.12.19) R < 9.5 nmi R_T = 20,000 ft	Active GPC (¶2.13.5) R > 9.5 nmi R_T = 600,000 ft Active GPC (¶2.13.4) R < 9.5 nmi R_T = 40,000 ft

*GPC & auto mode same

R_D = Range Designate; R_T = Range of Target; Paragraphs refer to Hughes TS 32012-076 (EA-2 ATP)

Table 10. False Alarm Rate

Designated Ranges		Search	Acquisition	Track
nmi	ft.			
> 18.9	> 114,912			
9.3 - 18.9	56,544 to 114,912	Passive GPC (Para. 2.5.3) R_D = 98,000 ft.		
7.2 - 9.3	43,776 to 56,544			
3.8 - 7.2	23,104 to 43,776	Passive GPC (Para. 2.5.3) R_D = 28,000 ft.		
1.9 - 3.8	11,552 to 23,104	Passive GPC (Para. 2.5.3) R_D = 18,000 ft.		
0.95 - 1.9	5,776 to 11,552	Passive GPC (Para. 2.5.3) R_D = 8,000 ft.		
0.42 - 0.95	2,554 to 11,552	Passive GPC (Para. 2.5.3) P_D = 4,000 ft.		
0.016 - 0.42	97 - 2.554	Passive GPC (Para. 2.5.1) R_D = 1,000 ft.		
		Active (Para. 2.5.2) R_T = 1,000 ft. Manual/Auto (Para. 2.5.4)		

R_D = Range Designate; R_T = Range of Target; Paragraphs refer to Hughes TS 32012-076 (EA-2 ATP)

Table 11. Summary of Untested EA-2 Rockwell Specification Paragraphs

Item Number	Paragraph Number	Pargraph Title
1.	4C.3.1.2.4.1.2	Controls and Status Discretes (EA-1A Interface)
	Output: b.	Lobing Enable
	c.	Lobing Alpha/Beta
	d.	Lobing Phase 0 - 180°
2.	40.3.1.2.4.2.1	Controls and Status Discretes (DA-A Interface)
	e.	Radar Sum Enable
	f.	Radar Difference Enable
	h.	Transmitter Limiter AGC
	i.	First IF Step AGC
3.	40.3.2.1.2.3.2	GPC Designate, Passive Mode (TBS)
4.	40.3.2.1.2.3.3.2	Acquisition Phase (Autotrack, Passive Mode)
5.	40.3.2.1.2.5.1	Parameter Measurement Accuracy Convergence Time
6.	40.3.2.1.2.5.2	Measurement Data Output Sample Rate
7.	40.3.2.1.2.6	Clutter Performance

6.3.2 EA-2 Conclusions/Recommendations

The amount of testing performed on the ADL EA-2 is more than adequate to ensure that the ADL EA-2 will meet its mission of verifying Shuttle interfaces. The prerelease version of the EA-2 ATP is an excellent start towards producing a comprehensive ATP.

Axiomatix does recommend, however, that some functional tests be conducted as a function of bus voltage and that the testing oversights listed in Table 11 be addressed by modifying the EA-2 ATP.

7.0 EFFECTS OF CROSS-COUPLING ON THE STABILITY AND TRACKING PERFORMANCE OF α/β SERVO LOOPS

7.1 Introduction

The Ku-band Communication Autotrack system contains α and β servo loops whose purpose is to acquire and track the difference azimuth and elevation error angles, respectively. Cross-coupling between the difference elevation and azimuth channels which feed these loops, originating from the monopulse feeds and comparator network, can cause stability problems during acquisition and tracking operations. Furthermore, even if stable operation is assured, the cross-coupling produces a degrading effect on each loop's tracking performance in noise.

This section discusses the potential stability problem caused by cross-coupling and derives a necessary but insufficient condition to ensure stability. In addition, using mean-square phase jitter as a measure of tracking performance, the degradation in this measure caused by cross-coupling is assessed in terms of such parameters as servo noise bandwidth and damping factor for all the loops, and the pair of cross-coupling gains.

We begin our analysis by considering the noise-free model of the pair of cross-coupled loops with the purpose of examining each loop's response to an input phase step. The behavior of the corresponding loop phase error responses as time approaches infinity is then an indication of system stability.

7.2 Noise-Free Model of Coupled Loops (Response to Phase Step Input)

Consider the noise-free model for the cross-coupled α and β servo loops, as illustrated in Figure 4. Here α and β denote the angular errors (in radians) for the two servo loops, and ε_α and ε_β are, respectively, the corresponding α-axis and β-axis voltage errors. The gains K_α and K_β are equivalent to $K_{sc} = K_{sc1}K_{sc2}$ in the Hughes servo configuration single-axis block diagram, where $K_{sc1} = 117.3$ V/rad and $1 \leq K_{sc2} \leq 15$. Since Figure 4 is an equivalent block diagram for the linear region of behavior, then, in reality, K_{sc} represents the slope of the two tracking characteristics at the origin, i.e.,

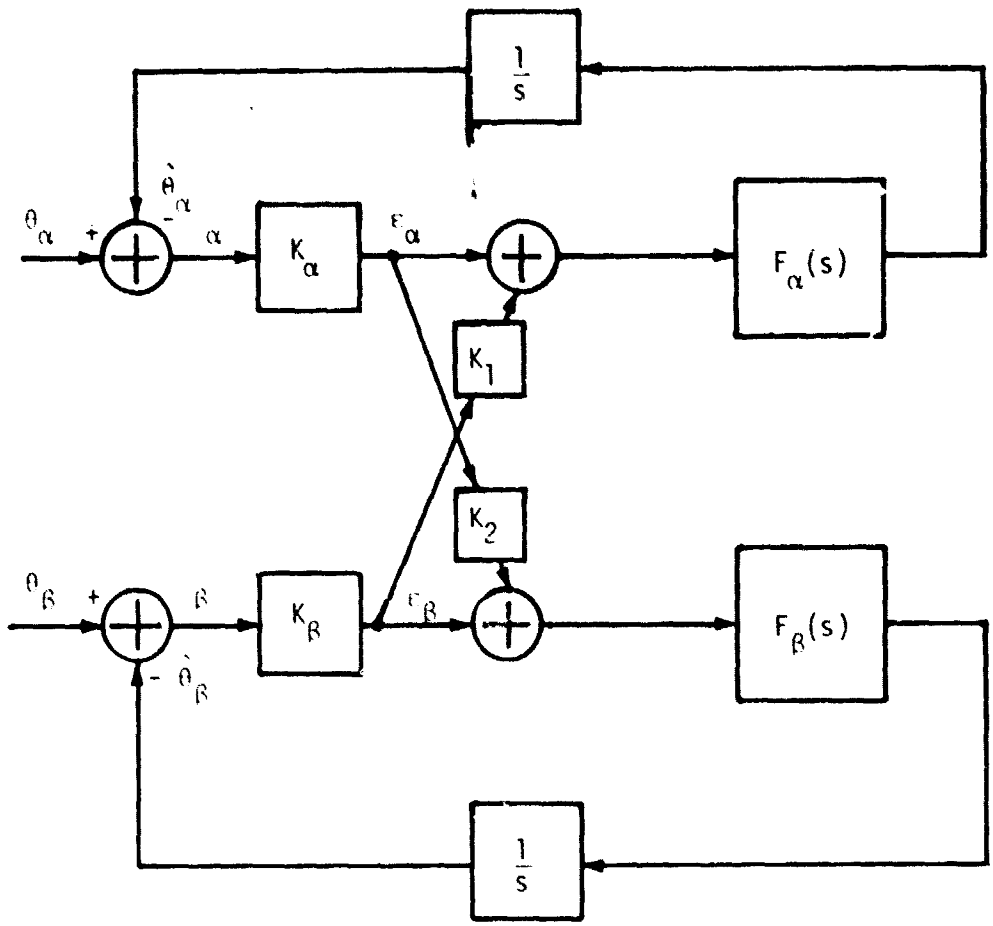

Figure 4. A Simple Block Diagram for the Cross-Coupled α and β Servo Loops in the Absence of Noise

$$117.3 < \frac{d\epsilon_\alpha}{d\alpha} < \underbrace{1759.5}_{(117.3)(15)} \quad ; \quad 117.3 < \frac{d\epsilon_\beta}{d\beta} < 1759.5 \tag{1}$$

we also have the equivalent relations

$$117.3\alpha \leq \epsilon_\alpha \leq 1759.5\alpha \quad ; \quad 117.3\beta \leq \epsilon_\beta \leq 1759.5\beta \tag{2}$$

The blocks labeled K_1 and K_2 represent the normalized cross-coupling between the loops where, for the moment, we only restrict K_1 and K_2 so that each has a magnitude less than or equal to unity. The blocks marked 1/s represent the transfer functions of the α- and β-axis servo motors. Finally, $F_\alpha(s)$ and $F_\beta(s)$ represent the composite transfer functions of the various components and subloops which make up the rate stabilization loop for each axis. Later on, we shall go into the detail necessary to characterize $F_\alpha(s)$ and $F_\beta(s)$ in terms of the actual rate stabilization loop parameters. For the moment, we shall just treat $F_\alpha(s)$ and $F_\beta(s)$ as rational transfer functions in much the same manner as one characterizes a loop filter in a conventional phase-lock-loop.

By inspecting Figure 4, we can immediately write the following relations:

$$\epsilon_\alpha = K_\alpha(\theta_\alpha - \hat{\theta}_\alpha) \quad ; \epsilon_\beta = K_\beta(\theta_\beta - \hat{\theta}_\beta) \tag{3}$$

$$\hat{\theta}_\alpha = \frac{F_\alpha(s)}{s}(\epsilon_\alpha + K_1\epsilon_\beta) \; ; \hat{\theta}_\beta = \frac{F_\beta(s)}{s}(\epsilon_\beta + K_2\epsilon_\alpha) \tag{4}$$

Combining (3) and (4) gives the pair of coupled equations

$$\epsilon_\alpha(s + K_\alpha F_\alpha(s)) = s K_\alpha \theta_\alpha - K_\alpha K_1 F_\alpha(s) \epsilon_\beta$$

$$\epsilon_\beta(s + K_\beta F_\beta(s)) = s K_\beta \theta_\beta - K_\beta K_2 F_\beta(s) \epsilon_\alpha \tag{5}$$

Letting θ_α and θ_β now correspond to step changes in phase, i.e.,

$$\theta_\alpha = \frac{\Theta_\alpha}{s} \quad ; \quad \theta_\beta = \frac{\Theta_\beta}{s} \tag{6}$$

then substituting (6) into (5) and solving for ε_α and ε_β yields, upon simplification,

$$\varepsilon_\alpha = \frac{K_\alpha\left[s + K_\beta\ F_\beta(s)\right]\Theta_\alpha}{\left[s + K_\alpha F_\alpha(s)\right]\left[s + K_\beta F_\beta(s)\right] - K_\alpha K_\beta K_1 K_2 F_\alpha(s)\ F_\beta(s)}$$

$$\varepsilon_\beta = \frac{K_\beta\left[s + K_\alpha\ F_\alpha(s)\right]\Theta_\beta}{\left[s + K_\beta F_\beta(s)\right]\left[s + K_\alpha F_\alpha(s)\right] - K_\alpha K_\beta K_1 K_2 F_\alpha(s)\ F_\beta(s)} \tag{7}$$

Note that, for no cross-coupling, i.e., $K_1 = K_2 = 0$, (7) reduces to

$$\varepsilon_\alpha = \frac{\Theta_\alpha}{s + K_\alpha F_\alpha(s)} = \left[1 - \frac{K_\alpha\ F_\alpha(s)}{s + K_\alpha F_\alpha(s)}\right]\left(\frac{\Theta_\alpha}{s}\right)$$

$$\varepsilon_\beta = \frac{\Theta_\beta}{s + K_\beta F_\beta(s)} = \left[1 - \frac{K_\beta\ F_\beta(s)}{s + K_\beta F_\beta(s)}\right]\left(\frac{\Theta_\beta}{s}\right) \tag{8}$$

as it should. The results in (7) can be written in a more compact form by defining the closed-loop transfer functions in the absence of cross-coupling, i.e.,

$$H_\alpha(s) = \frac{K_\alpha\ F_\alpha(s)}{s + K_\alpha\ F_\alpha(s)}$$

$$H_\beta(s) = \frac{K_\beta\ F_\beta(s)}{s + K_\beta\ F_\beta(s)} \tag{9}$$

Dividing the numerator and denominator of the right-hand side of (7) and using (9) gives the desired result, namely,

$$\varepsilon_\alpha(s) = \frac{\left[1 - H_\alpha(s)\right]\left(\frac{\Theta_\alpha}{s}\right) - K_1 H_\alpha(s)\left[1 - H_\beta(s)\right]\left(\frac{\Theta_\beta}{s}\right)}{1 - K_1 K_2 H_\alpha(s) H_\beta(s)}$$

$$\varepsilon_\beta(s) = \frac{\left[1 - H_\beta(s)\right]\left(\frac{\Theta_\beta}{s}\right) - K_2 H_\beta(s)\left[1 - H_\alpha(s)\right]\left(\frac{\Theta_\alpha}{s}\right)}{1 - K_1 K_2 H_\alpha(s) H_\beta(s)} \tag{10}$$

To examine system stability, we consider the steady state ($t \to \infty$) behavior of the angular error voltages in response to the step changes in phase of (6). Applying the final value theorem to (10), we observe that, if they exist, the limiting values of ε_α and ε_β become

$$\lim_{t\to\infty} \varepsilon_\alpha(t) = \lim_{s\to 0} s\varepsilon_\alpha(s); \quad \lim_{t\to\infty} \varepsilon_\beta(t) = \lim_{s\to 0} s\varepsilon_\beta(s) \tag{11}$$

or

$$\lim_{t\to\infty} \varepsilon_\alpha(t) = \lim_{s\to 0} \frac{\left[1 - H_\alpha(s)\right] \Theta_\alpha - K_1 H_\alpha(s)\left[1 - H_\beta(s)\right]\Theta_\beta}{1 - K_1 K_2 H_\alpha(s) H_\beta(s)}$$

$$\lim_{t\to\infty} \varepsilon_\beta(t) = \lim_{s\to 0} \frac{\left[1 - H_\beta(s)\right] \Theta_\beta - K_1 H_\beta(s)\left[1 - H_\alpha(s)\right]\Theta_\alpha}{1 - K_1 K_2 H_\alpha(s) H_\beta(s)} \tag{12}$$

Since, from (9),

$$\lim_{s\to 0} H_\alpha(s) = \lim_{s\to 0} H_\beta(s) = 1 \tag{13}$$

then, clearly, both $\varepsilon_\alpha(t)$ and $\varepsilon_\beta(t)$ will have limiting values of zero, i.e., a stable situation results in the steady state, if

$$1 - K_1K_2 > 0 \tag{14}$$

or

$$\boxed{K_1K_2 < 1} \tag{15}$$

Stated in words, (15) says that, for the pair of cross-coupled loops as modeled in Figure 4, a necessary (but insufficient) condition for each loop to acquire a phase input step is that the product of the relative cross-coupling gains be less than one. Note that this result has been obtained independent of the order of each of the uncoupled loops, i.e., it has not been necessary to restrict $H_\alpha(s)$ and $H_\beta(s)$ to obtain first- or second-order polynomials as denominators as would be the case for first- and second-order loops.

To say any more about loop stability, one must investigate the pole locations of $\varepsilon_\alpha(s)$ and $\varepsilon_\beta(s)$, which requires investigation of the roots of the denominator $1 - K_1 K_2 H_\alpha(s) H_\beta(s)$. This, in turn, requires specifying the equivalent loop filters $F_\alpha(s)$ and $F_\beta(s)$. Due to the complex form of the transfer functions which represent these filters (as we shall see later on), we shall not pursue the stability question any further. In the next section on tracking behavior in the presence of noise, however, it will be necessary to assume a particular functional form for $F_\alpha(s)$ and $F_\beta(s)$. Since $F_\alpha(s)$ and $F_\beta(s)$ are, in general, the ratio of high-order polynomials (this will be seen later on), we shall assume that only the first-order terms are significant and, thus, model these filter transfer functions as

$$F_\alpha(s) = K_{F_\alpha} \frac{1 + s\,\tau_{2\alpha}}{1 + s\,\tau_{1\alpha}} \quad ; \quad F_\beta(s) = K_{F_\beta} \frac{1 + s\,\tau_{2\beta}}{1 + s\,\tau_{1\beta}} \tag{16}$$

Such a model is equivalent to assuming that each of the uncoupled loops act as a second-order servo. Even under this relatively simplistic model, we shall see that the specification of tracking behavior in terms of the mean-square angular error involves extremely complex algebraic manipulations as a result of the presence of cross-coupling. Nevertheless, we shall pursue the results for this case, if only to give a qualitative indication of what might be expected if one were to consider higher order terms in $F_\alpha(s)$ and $F_\beta(s)$.

7.3 Noise Model of Coupled Loops (Tracking Analysis)

Consider the noise model of the coupled α and β servo loops, as illustrated in Figure 5. Here, $K_{\alpha 1}$ and $K_{\alpha 2}$ are identical to K_{sc1} and K_{sc2}, as previously defined. Similarly, $K_{\beta 1}$ and $K_{\beta 2}$ are identical to K_{sc1} and K_{sc2}. Furthermore,

$$K_\alpha = K_{\alpha 1} K_{\alpha 2} \quad ; \quad K_\beta = K_{\beta 1} K_{\beta 2} \tag{17}$$

Analogous to (3), we now have

$$\varepsilon_\alpha = K_\alpha(\theta_\alpha - \hat{\theta}_\alpha) + K_{\alpha 2} N_\alpha \quad ; \quad \varepsilon_\beta = K_\beta(\theta_\beta - \hat{\theta}_\beta) + K_{\beta 2} N_\beta \tag{18}$$

whereas (4) still applies. Again combining (18) and (4) gives the pair of coupled equations

$$\varepsilon_\alpha(s + K_\alpha F_\alpha(s)) = s K_\alpha \theta_\alpha - K_\alpha K_1 F_\alpha(s)\varepsilon_\beta + s K_{\alpha 2} N_\alpha$$

$$\varepsilon_\beta(s + K_\beta F_\beta(s)) = s K_\beta \theta_\beta - K_\beta K_2 F_\beta(s)\varepsilon_\alpha + s K_{\beta 2} N_\beta \tag{19}$$

Since we are interested here in the mean-square angular-tracking jitter due to noise, we may ignore the terms of (19) which involve θ_α and θ_β and directly solve for ε_α and ε_β. Doing so results, after some simplification, in a pair of equations analogous to (10), namely,

$$\varepsilon_\alpha = \frac{-K_1 K_{\beta 2} H_\alpha(s)\left[1 - H_\beta(s)\right] N_\beta + K_{\alpha 2}\left(1 - H_\alpha(s)\right) N_\alpha}{1 - K_1 K_2 H_\alpha(s)\, H_\beta(s)}$$

$$\varepsilon_\beta = \frac{-K_2 K_{\alpha 2} H_\beta(s)\left[1 - H_\alpha(s)\right] N_\alpha + K_{\beta 2}\left(1 - H_\beta(s)\right) N_\beta}{1 - K_1 K_2 H_\alpha(s)\, H_\beta(s)} \tag{20}$$

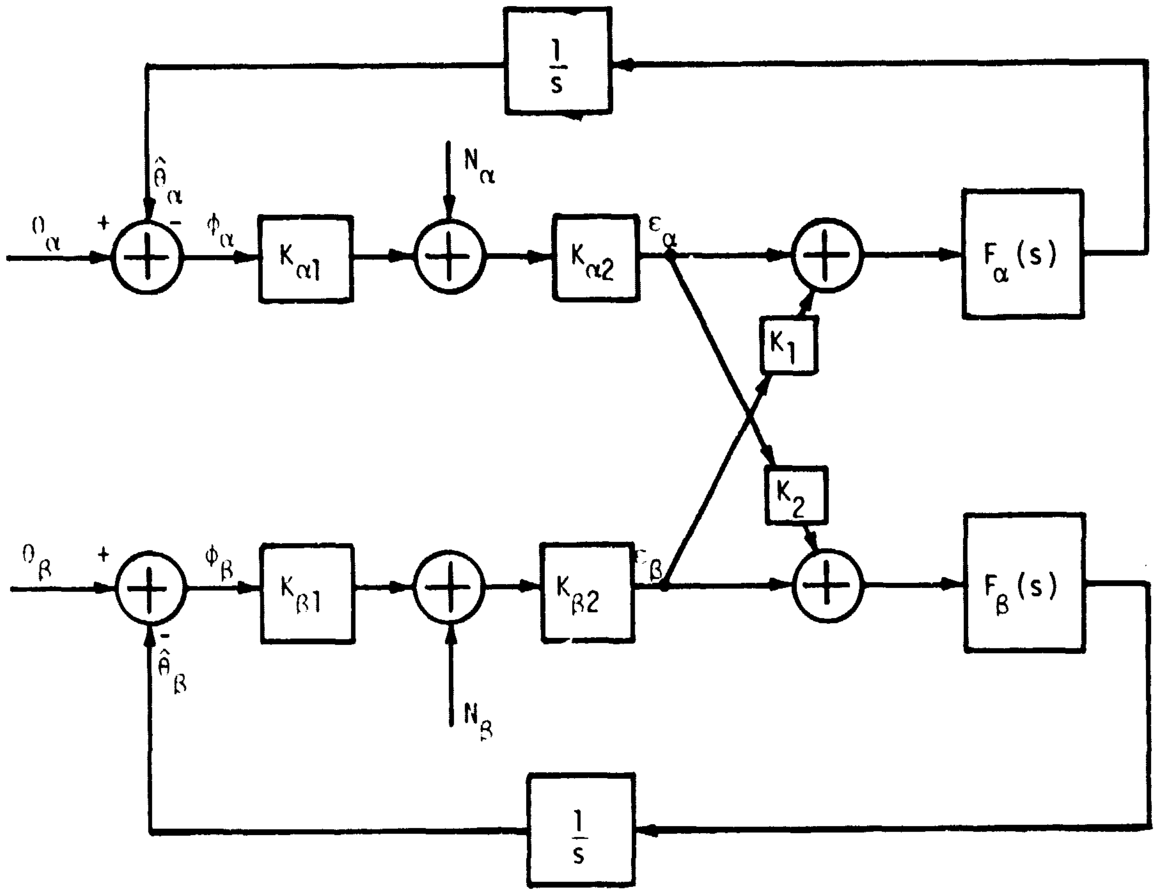

Figure 5. A Simple Block Diagram for the Cross-Coupled α and β Servo Loops in the Presence of Noise

In the absence of cross-coupling $\left(\text{i.e., } K_1 = K_2 = 0\right)$, (20) reduces to

$$\varepsilon_\alpha = K_{\alpha 2}\left(1 - H_\alpha(s)\right)N_\alpha \quad ; \quad \varepsilon_\beta = K_{\beta 2}\left(1 - H_\beta(s)\right) \tag{21}$$

as it should; that is, the noise sources are transformed by the out-of-band loop transfer functions insofar as their effect on the loop error voltage is concerned.

Actually, we are interested in the angular errors ϕ_α and ϕ_β which, from Figure 5, are related to ε_α and ε_β by

$$\phi_\alpha = \frac{\varepsilon_\alpha - K_{\alpha 2} N_\alpha}{K_\alpha} \quad ; \quad \phi_\beta = \frac{\varepsilon_\beta - K_{\beta 2} N_\beta}{K_\beta} \tag{22}$$

Substituting (20) into (22) and simplifying produced the desired results, namely,

$$\phi_\alpha = \frac{-\frac{K_1 K_{\beta 2}}{K_\alpha} H_\alpha(s)\left[1 - H_\beta(s)\right]N_\beta - \frac{1}{K_{\alpha 1}} H_\alpha(s)\left[1 - K_1 K_2 H_\beta(s)\right]N_\alpha}{1 - K_1 K_2 H_\alpha(s) H_\beta(s)}$$

$$\phi_\beta = \frac{-\frac{K_2 K_{\alpha 2}}{K_\beta} H_\beta(s)\left[1 - H_\alpha(s)\right]N_\alpha - \frac{1}{K_{\beta 1}} H_\beta(s)\left[1 - K_1 K_2 H_\alpha(s)\right]N_\beta}{1 - K_1 K_2 H_\alpha(s) H_\beta(s)} \tag{23}$$

We wish to compare the mean-square values of ϕ_α and ϕ_β in (23) relative to the same values for $K_1 = K_2 = 0$ so as to assess the degradation in mean-square phase jitter due to the cross-coupling effect. First setting $K_1 = K_2 = 0$ in (23), we get*

*From here on, we shall consider the performance of the α-channel only since, clearly, the equations have perfect symmetry with respect to α and β.

$$\sigma_{\phi_0}^2 = \frac{(N_{0\alpha}/2)}{K_{\alpha 1}^2}\left[\frac{1}{2\pi j}\int_{-j\infty}^{j\infty}\left|H_\alpha(s)\right|^2 ds\right] \triangleq \frac{N_{0\alpha} B_{L\alpha}}{K\alpha_1^2} \triangleq \frac{1}{\rho_\alpha} \tag{24}$$

where $B_{L\alpha}$ is the equivalent loop noise bandwidth of the α-servo in the absence of cross-coupling and the zero subscript on σ_ϕ^2 denotes this case. Furthermore, $N_{0\alpha}$ is the single-sided noise spectral density of the equivalent noise source $N_\alpha(t)$. In the presence of cross-coupling, we obtain from (23) the relation

$$\sigma_\phi^2 = \frac{(N_{0\alpha}/2)K_1^2 \; K_{\beta 2}^2}{K_\alpha^2}\left[\frac{1}{2\pi j}\int_{-j\infty}^{j\infty}\left|\frac{H_\alpha(s)\left[1 - H_\beta(s)\right]}{1 - K_1K_2H_\alpha(s)H_\beta(s)}\right|^2 ds\right]$$

$$+ \frac{(N_{0\alpha}/2)}{K_{\alpha 1}^2}\left[\frac{1}{2\pi j}\int_{-j\infty}^{j\infty}\left|\frac{H_\alpha(s)\left[1 - K_1 K_2 H_\beta(s)\right]}{1 - K_1 K_2 H_\alpha(s)\, H_\beta(s)}\right|^2 ds\right] \tag{25}$$

For the assumed loop filter transfer functions of (16), the closed-loop transfer functions of (9) can be written in the form

$$H_\alpha(s) = \frac{1 + \left(\frac{r_\alpha+1}{4B_{L\alpha}}\right)s}{1 + \left(\frac{r_\alpha+1}{4B_{L\alpha}}\right)s + \frac{1}{r_\alpha}\left(\frac{r_\alpha+1}{4B_{L\alpha}}\right)^2 s^2} = \frac{1+\tau_{2\alpha}\, s}{1 + \tau_{2\alpha} s + \frac{1}{r_\alpha}\tau_{2\alpha}^2\, s^2}$$

$$H_\beta(s) = \frac{1 + \left(\frac{r_\beta+1}{4B_{L\beta}}\right)s}{1 + \left(\frac{r_\beta+1}{4B_{L\beta}}\right)s + \frac{1}{r_\beta}\left(\frac{r_\beta+1}{4B_{L\beta}}\right)^2 s^2} = \frac{1+\tau_{2\beta}\, s}{1 + \tau_{2\beta} s + \frac{1}{r_\beta}\tau_{2\beta}^2\, s^2} \tag{26}$$

where $r_\alpha = 4\zeta_\alpha^2$ and $r_\beta = 4\zeta_\beta^2$, with ζ_α and ζ_β the damping factors for the α and β loops, respectively. Substituting (26) into the integrands of (25), we can express each of them as the ratio of two polynomials in s.

Thus, after much simplification, we obtain the following results:

$$\frac{H_\alpha(s)\left[1 - H_\beta(s)\right]}{1 - K_1 K_2 H_\alpha(s)\, H_\beta(s)} = \frac{a_0 + a_1 s + a_2 s^2 + a_3 s^3}{b_0 + b_1 s + b_2 s^2 + b_3 s^3 + b_4 s^4} \tag{27}$$

where

$$\begin{aligned}
a_0 &= 0 \\
a_1 &= 0 \\
a_2 &= \frac{1}{r_\beta}\tau_{2\beta}^{\ 2} = \tau_{2\alpha}^{\ 2}\left(\frac{1}{r_\beta}\xi^2\right) \\
a_3 &= \frac{1}{r_\beta}\tau_{2\beta}^{\ 2}\,\tau_{2\alpha} = \tau_{2\alpha}^{\ 3}\left(\frac{1}{r_\beta}\xi^2\right) \\
b_0 &= \eta \\
b_1 &= \left(\tau_{2\alpha} + \tau_{2\beta}\right)\eta = \tau_{2\alpha}\,\eta\,(1+\xi) \\
b_2 &= \frac{1}{r_\alpha}\tau_{2\alpha}^{\ 2} + \frac{1}{r_\beta}\tau_{2\beta}^{\ 2} + \eta\,\tau_{2\alpha}\tau_{2\beta} = \tau_{2\alpha}^{\ 2}\left(\frac{1}{r_\alpha} + \frac{1}{r_\beta}\xi^2 + \eta\xi\right) \\
b_3 &= \frac{1}{r_\alpha}\tau_{2\alpha}^{\ 2}\,\tau_{2\beta} + \frac{1}{r_\beta}\tau_{2\beta}^{\ 2}\,\tau_{2\alpha} = \tau_{2\alpha}^{\ 3}\left(\frac{1}{r_\alpha}\xi + \frac{1}{r_\beta}\xi^2\right) \\
b_4 &= \left(\frac{1}{r_\beta}\tau_{2\beta}^{\ 2}\right)\left(\frac{1}{r_\alpha}\tau_{2\alpha}^{\ 2}\right) = \tau_{2\alpha}^{\ 4}\left(\frac{1}{r_\alpha r_\beta}\xi^2\right)
\end{aligned} \tag{28}$$

with

$$\boxed{\begin{aligned}
\eta &\triangleq 1 - K_1K_2 \\
\xi &\triangleq \frac{\tau_{2\beta}}{\tau_{2\alpha}} = \frac{B_{L\alpha}}{B_{L\beta}}\left(\frac{r_\alpha+1}{r_\beta+1}\right)
\end{aligned}} \tag{29}$$

Also,

$$\frac{H_\alpha(s)\left[1 - K_1 K_2 H_\beta(s)\right]}{1 - K_1 K_2 H_\alpha(s)\, H_\beta(s)} = \frac{c_0 + c_1 s + c_2 s^2 + c_3 s^3}{d_0 + d_1 s + d_2 s^2 + d_3 s^3 + d_4 s^4} \tag{30}$$

where

$$c_0 = \eta$$
$$c_1 = \left(\tau_{2\alpha} + \tau_{2\beta}\right)\eta = \tau_{2\alpha}\eta(1+\xi)$$
$$c_2 = \frac{1}{r_\beta}\tau_{2\beta}^{\ 2} + \tau_{2\alpha}\tau_{2\beta}\eta = \tau_{2\alpha}^{\ 2}\left(\frac{1}{r_\beta}\xi^2 + \eta\xi\right)$$
$$c_3 = \frac{1}{r_\beta}\tau_{2\beta}^{\ 2}\tau_{2\alpha} = \tau_{2\alpha}^{\ 3}\left(\frac{1}{r_\beta}\xi^2\right)$$
$$d_0 = \eta$$
$$d_1 = c_1$$
$$d_2 = c_2 + \frac{1}{r_\alpha}\tau_{2\alpha}^{\ 2} = \tau_{2\alpha}^{\ 2}\left[\frac{1}{r_\alpha} + \frac{1}{r_\beta}\xi^2 + \eta\xi\right]$$
$$d_3 = c_3 + \frac{1}{r_\alpha}\tau_{2\alpha}^{\ 3}\xi = \tau_{2\alpha}^{\ 3}\left[\frac{1}{r_\alpha}\xi + \frac{1}{r_\beta}\xi^2\right]$$
$$d_4 = \left(\frac{1}{r_\beta}\tau_{2\beta}^{\ 2}\right)\left(\frac{1}{r_\alpha}\tau_{2\alpha}^{\ 2}\right) = \tau_{2\alpha}^{\ 4}\left(\frac{1}{r_\alpha r_\beta}\xi^2\right) \qquad (31)$$

Complex integrals of the type required in (25) have previously been evaluated [4]. In particular, since the denominator in both cases is a fourth-order polynomial, the following result applies:

For

$$P(s) = p_0 + p_1 s + p_2 s^2 + p_3 s^3$$
$$Q(s) = q_0 + q_1 s + q_2 s^2 + q_3 s^3 + q_4 s^4 \qquad (32)$$

then

$$I_4 \triangleq \frac{1}{2\pi j}\int_{-j\infty}^{j\infty} \frac{P(s)\,P(-s)}{Q(s)\,Q(-s)}\,ds = \frac{1}{2\pi j}\int_{-j\infty}^{j\infty} \left|\frac{P(s)}{Q(s)}\right|^2 ds$$

$$= \frac{p_3^{\ 2}\left(-q_0^{\ 2}q_3 + q_0q_1q_2\right) + \left(p_2^{\ 2} - 2p_1p_3\right)q_0q_1q_4 + \left(p_1^{\ 2} - 2p_0p_2\right)q_0q_3q_4 + p_0^{\ 2}\left(-q_1q_4^{\ 2} + q_2q_3q_4\right)}{2q_0q_4\left(-q_0q_3^{\ 2} - q_1^{\ 2}q_4 + q_1q_2q_3\right)} \qquad (33)$$

Equating the coefficient sets $\{p_i\}$ and $\{q_i\}$ with either $\{a_i\}$ and $\{b_i\}$ or $\{c_i\}$ and $\{d_i\}$, then (33) can be used to evaluate the two integrals required in (25). In particular, after considerable algebraic manipulation and simplification, we obtain the following results:

$$\frac{1}{2\pi j}\int_{-j\infty}^{j\infty}\left|\frac{H_\alpha(s)\left[1 - H_\beta(s)\right]}{1 - K_1 K_2 H_\alpha(s)\, H_\beta(s)}\right|^2 ds \;\triangleq\; 2B_{L\beta}\, K_{\beta\alpha}$$

$$\frac{1}{2\pi j}\int_{-j\infty}^{j\infty}\left|\frac{H_\alpha(s)\left[1 - K_1 K_2 H_\beta(s)\right]}{1 - K_1 K_2 H_\alpha(s)\, H_\beta(s)}\right|^2 ds \;\triangleq\; 2B_{L\alpha}\, K_{\alpha\alpha} \qquad (34)$$

where

$$K_{\beta\alpha} = \frac{\xi^2 r_\alpha^2 r_\beta + \xi^3(1+\xi)\left(\eta\, r_\alpha^3 r_\beta + \xi r_\alpha^2\right) + \xi^5 r_\alpha^3}{(r_\beta+1)\left\{r_\beta^2 + r_\alpha^2\xi^4 + \eta\xi(1+\xi)\left(r_\alpha r_\beta^2 + r_\alpha^2 r_\beta \xi\right) + \xi r_\alpha r_\beta\left[(1+\xi^2)(1-\eta) - 2\eta\xi\right]\right\}}$$

$$K_{\alpha\alpha} = \frac{r_\beta^2(1+\eta r_\alpha) + r_\alpha^2(1+r_\alpha)\xi^4 + \eta\xi(1+\xi)\left[r_\alpha r_\beta^2(1+\eta r_\alpha) + r_\alpha^2\, r_\beta(1+ r_\alpha)\xi\right] + \xi\, r_\alpha r_\beta\left[(1+r_\alpha-\xi)(1-\eta) - (1+r_\alpha)2\eta\xi\right]}{(r_\alpha+1)\left\{r_\beta^2 + r_\alpha^2\xi^4 + \eta\xi(1+\xi)\left(r_\alpha r_\beta^2 + r_\alpha^2 r_\beta\xi\right) + \xi\, r_\alpha r_\beta\left[(1+\xi^2)(1-\eta) - 2\eta\xi\right]\right\}} \qquad (35)$$

Note that, for $\eta = 1$, e.g., $K_2 = 0$, $K_1 \neq 0$, we have

$$K_{\alpha\alpha} = 1 \qquad (36)$$

in accordance with (24) and

$$K_{\beta\alpha} = \frac{r_\alpha\xi^2}{r_\beta\left(r_\beta+1\right)}\;\frac{\left[r_\beta + r_\alpha r_\beta\xi(1+\xi) + \xi^2(1+\xi) + r_\alpha\xi^3\right]}{\left\{\frac{r_\beta}{r_\alpha} + r_\beta\xi + \xi^2\left(r_\alpha + r_\beta - 2\right) + r_\alpha\xi^3 + \frac{r_\alpha}{r_\beta}\xi^4\right\}} \qquad (37)$$

which resembles a result for two-way phase-coherent tracking systems (see [5], eq. (3-18)).

Finally, combining (25) with (34) and using (24) gives the mean-square phase jitter of the angular error in the α-servo loop as

$$\boxed{\sigma_\phi^2 = \left(\frac{K_1^2 K_\beta^2}{K_\alpha^2}\right)\frac{K_{\beta\alpha}}{\rho_\beta} + \frac{K_{\alpha\alpha}}{\rho_\alpha}} \tag{38}$$

where, analogous to (24),

$$\rho_\beta \triangleq \frac{K_{\beta 1}^2}{N_{0\beta} B_{L\beta}} \tag{39}$$

is the β-servo loop SNR in the absence of cross-coupling

$F_\alpha(s)$ and $F_\beta(s)$ are currently being evaluated in terms of the rate stabilization loop parameters. Numerical results will be presented in a subsequent report.

8.0 AXIOMATIX COVERAGE OF THE DA ATP REVIEW MEETING

8.1 Introduction

As NASA is well aware, it has been difficult to relate the Rockwell Ku-band specification MC 409-0025, Rev. B, to the four Hughes acceptance test procedures (ATP's) because Hughes has written their own internal LRU specifications which differ significantly in format from the Rockwell document. To resolve this situation, a number of joint Axiomatix/Hughes/Rockwell meetings have been held over the past year in order to discuss and understand the EA-1, EA-2, SPA and DA ATP's.

Wayne McQuerry of Rockwell had previously reviewed the DA ATP and Hughes test specification 32012-042B in detail and generated 24 pages of comments, as shown in Appendix B. After Hughes studied the Rockwell comments, a series of four joint Axiomatix/Hughes/NASA/Rockwell meetings were held at Hughes.

8.2 Findings

In the initial meeting, Mal Meredith of Hughes designated Paul Sterba, also of Hughes, to keep the meeting minutes and specifically record action items, action item responsibilities, closures and conclusions. Appendix C is the Hughes memorandum summarizing the four days of the DA ATP joint meetings.

To restate the meeting results as summarized on page 1 of Appendix C, each Rockwell comment was discussed in detail and the appropriate action taken. A total of 123 comments were presented by Rockwell (Appendix B), with the following dispositions:

1. Hughes accepts comments and no action required (5)
2. Rockwell withdrew comments (9)
3. Hughes will change DA ATS per comment (29)
4. Hughes action defined (59)
5. Hughes/Rockwell action defined (8)
6. Rockwell action defined (13).

The only open issue is the subject of system test equipment (STE) calibration which is involved in five of the eight Hughes/Rockwell actions (item 5) and 12 of the 13 Rockwell actions (item 6). Hughes contends that calibrating the STE (that is, having metrology certify the STE output signals) would be prohibitively expensive, yet Rockwell contends that Q.C. will not allow "uncalibrated" equipment to be connected to flight hardware. Basically, Rockwell is not insisting that the STE be "certified" by metrology but, rather, that the STE be affixed with Q.C. or equivalent seals and the STE configuration be controlled by the formal Hughes documentation process. At the present time, Rockwell and Hughes are still discussing how to resolve the STE calibration issue.

8.3 Conclusions/Recommendations

The four joint DA ATP meetings provided an opportunity for non-Hughes personnel to gain an understanding of the DA ATP and, at the same time, the meetings were an excellent start in correlating the Hughes DA ATP with the Rockwell requirements. The net results of these four meetings are a start in producing a DA ATP that all parties will have confidence in and an ATP which will ensure that quality flight hardware is being delivered.

An important outfall of the meetings, which will have an impact on other areas of the Ku-band project, is Mal Meredith of Hughes insisting that his personnel record the meeting minutes and document the action items, action item responsibilities, closures and conclusions. At the end of the meeting, a working document was produced so that each party knew what was required of it. The previous problems of everyone leaving the meeting "feeling good" but not remembering what was committed to or accomplished have been avoided, with Hughes becoming more disciplined.

As previously stated, Axiomatix feels that the DA ATP joint meetings are an excellent start towards correlating the DA ATP with the Rockwell requirements, but Axiomatix still feels that the process should be carried one step further. Both the DA ATP and the Rockwell DA specification are lengthy documents and, to ensure that there are no "holes" in the DA LRU testing, Axiomatix recommends that a correlation matrix be generated.

REFERENCES

1. "Shuttle Orbiter Ku-Band Radar/Communications System Design Evaluation," Axiomatix Report No. R8012-3, Final Report on NASA/JSC Contract NAS 9-15795, dated December 22, 1980.

2. SPA LRU Development Specification #DS 32012-011, Rev. A.

3. Preliminary System Specification #HS 237-2781, dated May 19, 1980.

4. W. W. Seifert, C. W. Steeg, Jr., Editors, Control Systems Engineering, McGraw-Hill Book Co., Inc., NY,NY, 1980, pp 945-955. (This portion was reprinted from a laboratory report by R. C. Booton, Jr., M. V. Mathews and W. W. Seifert, MIT, 1953).

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APPENDIX A

HUGHES DEPLOYED ASSEMBLY ATP

AXIOMATIX MEMO DATED SEPTEMBER 11, 1980

Axiomatix

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File: Contract 16067 "A"

TO: Jim Kelly, EE3
NASA Lyndon B. Johnson Space Center
Tracking & Communications Development Division

FROM: R.G. Maronde

DATE: September 11, 1980

SUBJ: Hughes Deployed Assembly ATP

NASA has requested that Axiomatix review and comment upon Hughes test specification TS32012-Q42, Revision B, "Ku-Band Deployed Assembly (DA) Acceptance Test Specification with Appendices A,B,C,D,E,F." This acceptance test procedure (ATP) will be used by Hughes to demonstrate the DA LRU has been properly manufactured prior to delivery to Rockwell, whereas any qualification test procedure (QTP) will be used to verify the DA LRU design.

In the past, when requested to review ATP's or QTP's, Axiomatix has constructed a test verification matrix. Axiomatix has always assumed the baseline LRU design document to be the respective Rockwell equipment specifications. Therefore, the Axiomatix test verification matrix has one axis being the Rockwell specification paragraphs and the other axis being the tests listed in the ATP or QTP. Any "holes" in the testing program are readily apparent since unverified specification paragraphs are highlighted.

During this initial review of TS32012-Q42, Axiomatix did not construct a test verification matrix. Instead, the ATP was carefully read, along with the six appendices. The procedure contained many tests, detailed test set-up diagrams and data sheets which at first appeared to be very satisfactory. However, after rereading the ATP, the major question remaining was: What exactly did the procedure test or verify? Since Rockwell specification MC409-0025, Revision B with changes, "Integrated

Communications and Radar Equipment, Ku-Band," is the baseline document, a cursory search was conducted to determine whether there was any correspondence between the Rockwell specification paragraphs and the tests outlined in the DA ATP.

Before discussing the findings, an important point needs to be made. Some of Rockwell's vendors have always constructed their ATP's or QTP's in almost the same format as the test verification matrix presented in the corresponding Rockwell equipment specification. Constructing an Axiomatix test verification matrix, therefore, was straightforward because of the high degree of correlation between the Rockwell specification paragraphs and the ATP or QTP tests. The Axiomatix test verification matrix uncovered a number of "holes" in the testing program mainly because the precise Rockwell specification paragraphs being tested were readily ascertained.

Hughes, on the other hand, for some reason does not use the Rockwell test verification matrices presented in the Revision B Ku-band specification as a guide when writing test procedures. The result is a number of tests that may be good tests in their own right but which nevertheless may not be relevant to demonstrating Rockwell specification compliance. For example, during the Ku-band system verification for the ADL LRU's, the tests were such that one test may have verified a number of specification paragraphs and another test may have not verified any paragraphs.

As previously mentioned, the Axiomatix approach assumes the Rockwell specifications are the baseline documents. Therefore, since there is a low correlation in formats between the Rockwell Ku-band specification and the Hughes test procedures, constructing a test verification matrix is very time consuming. However, once constructed, these matrices in the past have shown an incredible number of "holes".

In the initial review of TS32012-Q42, there is no apparent correlation between the tests presented and the Rockwell Revision B paragraphs for the DA LRU. Axiomatix could construct a test verification matrix to ascertain exactly to what extent the Hughes ATP tests the DA, but the matrix presents two problems. The first problem is that, because of the low Rockwell specification/Hughes ATP correlation factor, constructing the matrix will be very time-consuming.

The second problem is that a large amount of controversy will be created. Axiomatix, Hughes and Rockwell will all have their own interpretations as to whether a test completely verifies a specific Rockwell specification paragraph.

Axiomatix feels TS32012-042 in its present form is inadequate to demonstrate conformance to the Rockwell Revision B specification. It is recommended that Hughes change the ATP format to reflect a high degree of correlation with the Rockwell documents, which will result in minimizing any controversy.

cc:

Jack Johnson, JSC
Wayne McQuerry, Rockwell International

APPENDIX B

ROCKWELL COMMENTS ON HUGHES DA ATP TS 32012-042B

Comments on TS32012-042B

These comments are divided into three parts as follows:

1. All sections of TS32012-042B except for the functional/performance tests per 3.2.3 through 3.2.4.25 and Appendices A through F.
2. Functional/performance tests per 3.2.3 through 3.2.4.25 and Appendices A through F.
3. Functional/performance requirements not addressed per 2 above.

Section 1 - All sections of TS32012-042B except for functional/performance tests.

Item	Page	Paragraph
1-1	2	2.

Change line 3 to read "...specifications and drawings listed...".

Delete last sentence.

Rationale: The ATP is a Type I document; drawings are Type II. Therefore, drawings cannot take precedence over the ATP.

1-2 20 and following:

Figures 3-1 through 3-9 except for 3-7. Descriptions of test set-up/test configuration are very general and, except the RF and IF inputs and outputs, it is impossible to identify inputs and outputs in terms of DA connector/pin and to determine the validity of these inputs/outputs for testing. Items of concern include those inputs/outputs where timing or polarity are critical and inputs/outputs drawing sufficient current to result in appreciable IR drop in the inter LRU cabling such as the following:

a) Encoder drive

b) Gyro spin motor excitation

c) Gyro primary excitation

d) (Possibly) positive and negative drivers (± 15 VDC)

TS32012-042B Review - Section 1 Comments (cont.)

Item	Page	Paragraph
1-2	20 and following (cont.)	

Other problems associated with incomplete definition of test set-up/test specimen configuration are identified in Section 2 comments. Revise figures and/or text to define test set-up/test configuration.

1-3	31	4.1.3

Change test to read as follows: "The sequence of tests shall be in the numerical order presented in this procedure except when the sequence is specifically defined elsewhere, e.g., Figure 3-11 or, in the case of functional/performance tests, the order of performing specific tests or measurements is identified as "optional" in the procedure. In event retest (other than merely repeating measurements just completed due to personnel error or test equipment malfunction where it is obvious that the error or malfunction could not overstress or otherwise damage the test specimen) or a modified testing sequence is required, testing shall be stopped and a Failure Report prepared. Testing shall be resumed as/if directed by disposition of the Failure Report."

1-4	33	4.2.2.1

Delete last sentence.

1-5	33	4.2.2.3

The post environmental monopulse phase verification test should be performed prior to the tests per 3.2.3 through 3.2.3.16.4.

1-6	34	4.2.4.3.2

What is purpose of "...in qual..."? Last sentence reads "...five 'limit'..." - Table 4-4 shows 8 limit values. Paragraph should be clarified.

TS32012-042B Review - Section 1 Comments (cont.)

Item	Page	Paragraph
1-7	35 36	4.2.4.4.9 Table 4-2

Exactly what functional tests are to be performed and when?; e.g., are tests performed per the "pre-vib" col. (Table 4-2) before each axis of vibration and per the "post vib" column after each axis of vibration? Clarify requirements.

Item	Page	Paragraph
1-8	35	4.2.4.4.5 5.3.5.5.6

Revise as required to reflect the following:

a) Define test specimen configuration insofar as input commands, i.e., define state of signals such as sum and difference ch. enable, HSR Select, alpha-beta and 0-180 lobing, polarization, etc.

b) Require verification that gimbal lock remains locked and transmitter remains off and that there is no intermittency or anomalous behavior of outputs monitored during vibration.

c) Check difference channel as well as sum channel during vibration-- either input signal into J5A as well as J4A or use self test function. (Self test function is preferred.)

d) Add the following outputs to the list monitored:

Alpha Axis High

Beta Axis High

Operate Status

Boom Stow Enable II

± 15 VDC (positive and negative drivers)

Data IF

Track IF

TS32012-042B Review - Section 1 Comments (cont.)

Item Page Paragraph

1-8 (cont.) Temperature Sensors

DEA Heater Current - both

Diode Current - alpha-beta lobing = alpha

e) Operating mode is Radar, ch. 3 throughout. MC calls for 1/2 time in radar, 1/2 time in comm. Radar mode only appears OK - MC change required.

f) RF input is J4A only so check sum ch. receiver only. Should use self test function and check both receivers. Could input signal into J5A as well as J4A but this is an unnecessary complexity.

g) Accept/reject criteria specified only for accelerameters, strain gages, bus current and DMA heater current and data sheets provide no entry for these items. Should verify the following during vibration and data sheets should provide entries for each:

(1) Gimbal lock remains locked.

(2) Transmitter does not cause an even momentarily.

(3) No intermittent conditions or anomalous behavior for all inputs and outputs monitored.

1-9 33 4.2.1 or ?

Add requirement (either para 4.2.1 or elsewhere) for weight per MC409-0025, para 4.2.2.1.

1-10 46 4.2.5 thru 4.2.5.3

Temperatures are defined for ATVT. Thermal CDR has not been conducted. Thermal environments may be revised as a result of CDR.

1-11 49 4.2.5.4.2.9 Table 4-2 does not define post TV tests. Per 4.2.2.3 post TV tests consist of all tests defined in Section 3. Revise Table 4-2 to show post TV tests or change 4.2.5.4.2.9 to "... perform tests per 3.2.3 through 3.2.4.25 ..."

SIZE	CODE IDENT NO.	DRAWING NO.
A	03953	

SCALE	REV	SHEET	OF

Item	Page	Paragraph	
1-12	-	-	No leakage test is performed. (Test per 3.2.3.2 is only a pressurization check.) A leak test in accordance with paragraph 4.2.2.5 of MC409-0025 is required after completion of environmental test.
1-13	-	--	Text implies DA is OFF during "cool-down". ATVT is an operating test so DA is to be ON throughout test unless required to be OFF during latter of "cool-down" only to achieve test temperatures in a reasonable time. When functional testing is not in progress, alternate between radar and comm operating modes so that approximatly half of test time is in each operating mode.
1-14	-	--	Transmitter ON/Off not defined during ATVT. Transmitter is to be ON throughout test except when functional testing requires it to be OFF or during "cool-down" if DA has to be OFF.
1-15	-	--	Add requirement to record temperatures, as indicated by DA temperature sensors, hourly during all testing except ATVT and every 15 minutes during ATVT. Add the necessary data sheets.
1-16	-	--	Add requirement to monitor inputs and outputs during ATVT when functional testing is not in progress, including temperature transitions, and verify no intermittent conditions or anomalous behavior.
1-17	32	4.1.6 (c)	Change tolerance for random vibration level from plus 3 dB, minus 1.5 dB to plus 1.0 dB, minus 3.0 dB.
1-18	31	4.1	Delete last sentence in first paragraph
1-19	32	4.1.4	Add sentence "whenever a Failure Report (Hughes Aircraft form 11873) is initiated, the Buyer shall be notified per PDRL RA 24."

TS32012-042B REVIEW - SECTION 2 COMMENTS

Item	Page	Paragraph
2-1	5	3.2.3.3.1-.1.6 Cannot verify lock motor drive signal level and polarity and loads for the ± 15 vdc outputs are compatible with EA-1. Either revise procedure, including data sheets to define these parameters or provide test equipment description/operating manuals or instructions and calibration requirements (as Type II data) which define these parameters.
2-2	7	3.2.3.3.3-.3.3 Power is radar standby (per 3.2.3.3.1.3) and gimbals are locked (per 3.2.3.3.1.6). Revise to define configuration for this test.
2-3	7	3.2.3.3.3-.3.3 Cannot verify inputs for gyro spin motor drive and gyro primary excitation and the load for gyro outputs are compatible with the requirements of EA-1 plus interconnecting wiring. Same as for item 2-1
2-4	7	3.2.3.3.3-3.3 The tolerance allowed (± 3.7%) is considerably greater than the ± 1% used in presentations on servo performance and must be justified since this test represents the primary verification of this critical parameter after exposure to AVT and ATVT. It appears that the "justification" could be relatively simple and would consist of a statement similar to the following (either in TM01A or the analysis report): "workmanship defects, component tolerance buildups/changes, etc. expected to be detected during acceptance testing (i.e., "aging", AVT, ATVT, etc.) and which could cause the scale factor to exceed design requirements (± 1%) would normally result in changes exceeding the ATP allowed tolerance (± 3.7%) because... In event the scale factor actually did exceed design requirements,

Item	Page	Paragraph
2-4	7	but did not exceed the ATP allowed tolerances, system performance degradation would not exceed ... " NOTE: This test is considered a satisfactory test for verifying the scale factor during DA acceptance testing and there is no intent to require a more sophisticated test. However, since the allowed tolerances exceed those used (to date) in defining system performance capabilities, these differences must be justified and the justification documented.
2-5	7	3.2.3.3.4-.4.2 The configuration is inadequately defined (per procedure the DA gimbals are still locked and in "standby" power) and level and polarity of encoder drive signal cannot be checked for compatibility with EA-1 output levels and wire drop. See previous comments concerning this type of discrepancy.
2-6	7	3.2.3.3.4-.4.2 Add requirement for visual verification that antenna is approximately at the commanded position, i.e., verify the antenna is, approximately, at 0,0 when 0,0 is commanded, etc. The purpose of this addition is to screen out wiring/polarity errors that could result in the antenna being at alpha = 0°, beta = -30° but readouts showing alpha = 0°, beta = + 30° and gross encoder "count" errors resulting in antenna being 0°, 60° and reading 0°, 30°. Figure 3-7 shows definition of + and - as well as alpha and beta.
2-7	7	3.2.3.3.5-5.2 The theory on which this test is based and how this measurement relates to items verified e.g., encoder accuracy/encoder MIP position, encoder rf axis alignment, etc and the overall accuracy associated with the test are not obvious.

TS32012-042B Review - Section 2 Comments (cont'd.)

Item	Page	Paragraph
2-7	(Cont'd.)	Provide a description of test and an error analysis defining actual errors associated with items verified by this test. Can be either in TM01A or a formally submitted report referenced in TM01A.
2-8	8	3.2.3.3.6-.6.4 No accept/reject criteria. Test proves little, if anything, about DA not covered by other tests. Instrumenting set up to provide essential information e. g., moments of inertia, motor torque scale factor, etc--would be very difficult and information required can be obtained by a relatively simple transfer function test.
		Retain main scan test--provides a "warm feeling". Delete miniscan unless this test can be revised to provide more useful information concerning DA performance capabilities.
2-9	8	3.2.3.3.7-.7.4
		(a) Configuration/inputs not adequately defined--see previous comments concerning this type problem
		(b) Scale factor tolerance (+ 4.9%) is greater than value used for servo analysis/ servo evaluation.
		Same comment as made per item 2-5 applies.
		(c) Add requirement to verify direction of travel as a function of motor drive polarity.
		Actually a part of (a) above.
		(d) The scale factor of 149 in-lbs/amp implies a shunt of 0.11114 ohms resistance.
		Does not seem reasonable--define test set-up.
		(e) Clarify procedures for determining friction from data. ESTL data shows 3.54 in.-lb. for alpha and 2.049 in.-lb. for beta; should show 17.66 in.-lb. for alpha and 5.96 in.-lb for beta.
2-10	9	3.2.3.3.8 No comment.

TS32012-042B Review-Section 2 Comments (Cont'd.)

Item	Page	Paragraph
2-11	10	3.2.3.4.2-.2.9 Procedure (3.2.3.4.2.1) says "Enable radar standby and radar on." Implying both commands to the DA are set HIGH simultaneously and both are HIGH for all measurements. The data sheets indicate current measurements are made for both standby and on configurations. Furthermore, both commands should not be HIGH simultaneously. Clarify procedure
2-12	10	3.2.3.4.2-.2.9 Add upper limits for power consumption--both standby and radar ON. These limits, for 28 vdc input, shall be 132 watts for standby and 275 watts for radar ON per the most recent SE08A. NOTE: SE08A erroneously shows the power consumption as DEA power consumption. MC409-0025 will be revised to reflect these values.
2-13	11	3.2.3.4.3-.3.3 Additional information required to verify proper response to frequency select A, B, C signals and compatibility with EA-2. See previous comments on configuration.
2-14	11	3.2.3.4.4-.4.5 (a) Change to reflect that <u>average</u> power is being measured. (b) Accept/reject criteria for high power would allow DA to "pass" even though output was significantly degraded. Change to reflect the required DEA output of 46.1 ± 1.3 dBm peak power output (reduced by duty cycle) and use actual coupler loss (carry forward data). (c) Tolerances of ± 3 dB for medium and low power appear to be unnecessary--Hughes has indicated compliance with the ± 2 dB requirements. Change to ± 2 dB. NOTE: If the hardware, as designed, will not comply with the ± 2 dB tolerance, Hughes should advise Rockwell and Rockwell will determine whether this requirement can be relaxed.

TS32012-042B Review - Section 2 Comments (Cont'd.)
2-14 (Cont'd.)

Item Page Paragraph

(d) What are the requirements (Hughes defined) for power output in the TWT by-pass mode?

DA LRU Spec requirements: 7.55 ± 1.45 dBm Peak

Early version of DEA ATP: 6.65 ± 2.25 dBm Peak

Present DA ATP (equivalent): 6.7 ± 5.0 dBm Peak

Hughes determine what requirements are and advise Rockwell. Change ATP as/if required. Rockwell will change MC409-0025 accordingly.

(e) Add accept/reject criteria for power monitor output for High and medium power. Use power monitor calibration (carry forward data) and set limits to confirm 46.1 ± 1.3 dBm peak output from DEA.

(f) Point for measurement not identified. Change procedure to specify J4A.

2-15 11 3.2.3.4.6 through 3.2.3.4.6.5 In several cases, as indicated below, requirements are confusing and text and data sheets do not seem to correlate.

Clarify procedures and requirements.

Examples of problems in reviewing this section are as follows:

(a) Paragraph 3.2.4.6.2 reads "...enable Comm A standby and Comm A on." Which command is the DA to receive?

(b) Line 7 on data sheet calls for "verification", "Comm A ON." How is this to be verified? Per (a) above have "enabled" both standby and ON.

(c) Line 4 on data sheet--is equipment in STANDBY or ON?

(d) Nomenclature for beam select signals not per DA input signals. Clarify when DA is receiving "wide beam select" and "wide beam transmit select" signals.

TS32012-0423 Review - Section 2 Comments (Cont'd.)

Item Page Paragraph

2-15 (Cont'd) (e) Line 6 of data sheet has no entry in "requirement" column: should be OFF or LOW apparently since the transmit enable signals appear later. Also, are Transmit Enable KUA and Transmit Enable Comm A both low, as data sheet implies, or is Transmit Enable Comm A HIGH and Transmit Enable KUA LOW as text implies?

(f) No apparent data sheet entry for verifying Operate Status signal is LOW when Transmit Enable Comm A is LOW and Transmit Enable KUA is HIGH.

(g) Line 10 of data sheet reads "Comm A-KUA", "Verification". What is being verified? How?

(h) What is configuration for current measurement per line 11? Is it as follows:

Comm A ON: HIGH

Transmit Enable Comm A: HIGH

Transmit Enable KUA: HIGH

Operate Status Signal: HIGH (or ON)

(i) Apparently no data sheet entry covering DA response to Transmit Enable 30 deg. deploy signal HIGH--i.e., operate status signal should be HIGH or ON.

2-16 11 3.2.3.4.6-.6.5 Change entry in requirements column for standby and on power consumption (current measurements) from "Data" to the maximum allowed value. These limits, for 28 vdc input, shall be 132 watts for standby and 308 watts for Comm on, per the most recent SE08A.

NOTE: SE08A erroneously shows the power consumption on "DEA" power consumption. MC409-0025 will be revised to reflect these values.

Item	Page	Paragraph
2-17	11	3.2.3.4.8-. (a) Definition of configuration is not clear. See previous comments pertaining to definition of configuration (b) Add measurement of time from exciter gate trailing edge to RF pulse trailing edge. Same delay requirements apply; or verify transmitted pulse width is same as exciter gate pulse width ± 20 nsec for pulse width ≥ 2.7 microseconds and ± 10 nsec for pulse width = 122 nsec per DA LRU spec, Para. 3.2.1.2.1.1.9. (c) Difference between time delay, as measured at J4A, and the requirement, which is specified at the antenna output, and the justification for only measuring at J4A must be covered by analysis.
2-18	12	3.2.3.4.9-.9.2 Actual configuration of test specimen difficult to determine. See previous comments
2-19	12	3.2.3.4.10 through 3.2.3.4.11.2 Configuration and requirements incompletely defined. See previous comments pertaining to this. Examples of problems encountered in reviewing this section include the following: (a) What are the levels of the 156 MHz and 1875 MHz inputs? These were adjusted earlier in the procedure but this could have been performed hours (or days?) prior to this test. (b) Antenna select commands are not relatable to DA inputs. (See 2-15 (d). (c) How much (over what range) is the 1875 MHz signal swept? (d) Over what frequency band is flatness verified? (e) What does "Mode 6" and "Mode 7" mean in terms of DA inputs?

Item	Page	Paragraph
2-20	12	3.2.3.4.10 through 3.2.3.4.11.2

(a) Change requirements to sweep the 1875 MHz signal over sufficient range to determine transmit 3 dB bandwidth. Record the 3 dB bandwidth for information (data) only.

(b) Change flatness requirement to 1 dB peak-to-peak (not ± 1 dB) over ± 112.5 MHz bandwidth.

(c) Change power monitor requirement from "reference" to specific accept limits. These limits shall be equivalent to the DEA output requirements. Coupler/monitor calibration data (carry forward data) shall be used to verify compliance with requirements.

(d) Change tolerance requirements for J4A and J5A measurements from ± 3 dB to ± 1.2 dB and use coupler calibration data to verify compliance.

2-21	13	3.2.3.4.12 through 3.2.3.4.12.10 This section must be revised to provide a more meaningful test. The test, as defined, does not verify a compatible interface with EA-2 for system self test purposes or provide an adequate check on performance of items not otherwise verified after exposure to test environments and during ATVT such as antenna difference channel circuitry, including the comparator, antenna sum channel circuitry, including the polarization switch, and rotating joints. All measurements, except for alpha-beta lobing current, state of the operate status signal and first LO frequency and amplitude, are identified either as "reference"--i.e., no accept/reject criteria--or the specified requirements are "applicable if measurable". The DA would "pass" the test with the comparator completely disconnected from the antenna difference channel elements and, if the requirements were applied literally, it would pass with the DEA signal source disconnected from the self test dipole.

Item	Page	Paragraph
2-21	13 (Cont'd.)	

Requirements applicable to the self test function include radar IF modulation (magnitude and phase or polarity) as a function of the lobing signals as well as radar IF level as a function of self test attenuator signals or commands.

Because of tolerances allowed for the various parts of the self test circuitry/components, it probably will be necessary to use data acquired during the pre-environment test as a baseline, or reference, and define requirements for subsequent tests--i.e., post vibration, during and after ATVT and post environment testing -- in terms of allowed changes from this baseline. These tests (tests after the initial, pre-environment exposure) would verify that exposure to the test environment did not degrade, or change, performance of the items checked only by the "self test" test beyond acceptable limits.

The DA self test capability provides a simple, fast, check of the exciter, receiver, antenna sum and difference channel circuitry, etc., and should be utilized between environment tests and during ATVT to minimize test time.

2-22 14 3.2.3.4.13 through 3.2.3.4.13.7 Test requirements and configuration not clear in some cases.

See previous comments on this item

Examples of problems encountered in reviewing this section include the following:

(a) Para. 3.2.3.4.13.3 says "Measure track IF frequency...". Data sheet has only one entry. What is RF input frequency (at J5A) and what is status of Frequency select A, B and C?

Item 2-22 Paragraph 3.2.3.4.13.3 (Cont'd.)

(b) Para 3.2.3.4.13.3 (and others) says "Verify passband..." but no requirements identified. Data sheet shows "X ± 10 MHz" (where "X" is nominal or center frequency for each channel) in requirement column. The only entries in the "test" and "re-test" columns for ESTL tests are "✓". Thus, presumably, the only item QC is to, or can, verify is that the input was swept over the required range--i, e., the test specimen would "pass" this test regardless of output.

(c) Para. 3.2.3.4.13.4 says Measure "...ripple modulation at the center frequency."

No definition of "ripple modulation at center frequency" is given.

No requirements (accept/reject criteria) shown.

No data sheet entries provided for this parameter.

What is QC supposed to verify?

(d) Are photographs of spectrum supposed to be made for 3.2.3.4.13.4 and 3.2.3.4.13.5?

Data sheet shows "passband (photos)" for 3.2.3.4.13.3 but there is no similar entry for 3.2.3.4.13.4 and 3.2.3.4.13.5.

ESTL data, both "test" and "retest" has photos for 3.2.3.4.13.4 and 3.2.3.4.13.5, but the photo for 3.2.3.4.13.4 in the "retest" data package submitted to Rockwell is unreadable ("white out") and is out of sequence.

(e) ESTL data for noise level measurements inconsistent; data shows difference channel levels of -30 dBm and -32 dBm for HSR= 1 and 0 respectively; gain data shows difference should be only 0.4dB. Data for sum channel is -34.5 dBm; noise figure and gain data show noise level should be approximately 2 dB higher than difference channel. Revise procedure as required to insure useful data. Add noise measurements for data and track IF's, comm freq. Make requirement dependent on measured gain to avoid problems associated with the allowed 8 dB gain variation allowed.

Item	Page	Paragraph
2-22 (Cont'd.)		(e) Para. 3.2.3.4.13.5 Same as (a) above except dealing with Radar IF in lieu of Track IF.
		(f) Para. 3.2.3.4.13.5 says "Repeat...for each of two second IF bandwidths". Data sheet shows entries for 10 MHz and 3 MHz bandwidths. Bandwidth determined by state of the High Sample Rate Select command to DA. How is QC to verify state of this command?
		NOTE: Test equipment description/"operating manual" and calibration requirements are not controlled (Type I) documents.
		(g) Para. 3.2.3.4.13.7 says "... measure...and ripple modulation." There is no data sheet entry covering this item. What is QC supposed to verify?
2-23	14	3.2.3.4.13 through 3.2.3.4.13.7
		(a) Gain tolerances of ± 6.0 dB and ± 6.5 dB are 2 dB greater than the tolerances per the DA LRU specification.
		MC409-0025 is being revised to reflect the DA LRU spec requirements. If the + 6.0 and ± 6.5 dB tolerances are retained in the ATP, Comm and Radar system performances must reflect these tolerances and MC409-0025 will have to be revised again (after Hughes has submitted analysis showing performance requirements are met with these tolerances.)
		(b) Add a requirement to record the ratio of the differnece channel gain to the sum channel gain, <u>including RF rotary joint losses</u> (SRJ carry forward data), and to verify that this ratio is within the limits of -2.2 ± 1.9 dB when no AGC is applied.
		(c) Add requirements to verify the bandwidths and ripple of all three IF meet the requirements specified in DA LRU spec, Para. 3.1.2.4.14.1 through 3.1.2.4.14.3 and 3.2.1.2.2.14.

TS32012-042B Review - Section 2 Comments (Cont'd.)

Item	Page	Paragraph
2-23	15	3.2.3.4.14 through 3.2.3.4.14.2

(a) The ATP does not reflect DA LRU Spec requirements as follows:

	DA LRU SPEC	ATP
TR Limeter AGC:	30 ± 1 dB	30 ± 1.5 dB
Step IF AGC:	30 ± 2 dB	30 ± 2.5 dB

MC409-0025 currently reflects DA LRU spec requirements.

Hughes define requirements and change ATP if required.

(MC409-0025 will be revised if the present ATP requirements are the "real" requirements.)

(b) For final (post environmental) test, measure response for both increasing and decreasing signal level.

(c) How is linear AGC slope to be determined?

Plot data and "eyeball" best straight line?

Use "least squares" mathametical computation??

Clarify procedure.

Item	Page	Paragraph
2-25	15	3.2.3.4.15 through 3.2.3.4.15.14

(a) S-Band Spur Rejection - Radar IF: The test requirements appear to be in excess of the requirements shown in the DA LRU Spec and MC409-0025.

Input, J4A:	+ 10 dBm	
Coupler effects:	- 22 dB	Nominal
Receiver Gain @ center Freq.	+ 81 dB	Nominal
Expected IF output if Frequency = center Freq:	+ 69 dBm	
Required output, ATP:	- 55 dBm	max; ch 1, 10 MHz BW
Implied rejection reqmt.:	124 dB	
Required rejection, DA LRU Spec:	45 dB	minimum

Hughes explain rationale for test requirements.

TS32012-042B Review - Section 2 Comments (Cont'd.)

Item	Page	Paragraph
2-25	15	3.2.3.4.15 through 3.2.3.4.15.14 (Cont'd.)

(b) Image frequency rejection - Radar IF: test requirements appear to be in excess of requirements per DA LRU Spec and MC409-0025.

Input, J4A:	+ 10 dBm	
Coupler effects:	- 22 dBm	Nominal
Receiver Gain (center freq.)	+ 81 dBm	Nominal
Expected IF level, Ctr. Freq. Input:	+ 69 dBm	
Required output, ATP	- 80 dBm max.	
Implied Rejection reqmt.	149 dB	
DA LRU Spec. reqmt.	70 dB	

Hughes explain rationale for test requirement

(c) S-Band Spur rejection and Comm Transmit Freq. rejection. Input is J4A only. Should be J5A for Track IF measurements and J4A for Data IF measurements. Track IF and Data IF tests, as defined, check sum channel recover only.

(d) Test access coupler characteristics: coupler characteristics are not defined. Must be defined at SRU level for the frequency band required for the test--carry forward data--and actual response used in determining rejection characteristics.

(e) Rejection requirements: in most cases requirements defined in terms of a maximum allowed IF signal level with an additional statement "or below noise level." Most data sheet entries for ESTL tests are simply "below noise level" or "BNL".

Change text and/or data sheets to require an entry showing rejection is greater than " X " dB when response is in the noise where "X" represents the minimum value that can be established due to noise level.

Item	Page	Paragraph
2-25	15	3.2.3.5.15 through 3.2.3.4.15.14 (Cont'd.)

(f) Comm transmit frequency rejection: rejection requirements must be justified. Minimum rejection implied is 103.5 dB for the track IF test as follows:

Input, J4A:	+ 10 dBm
Coupler effects:	- 22 dB Nominal
Receiver Gain, sum input to track IF:	+ 70.5 dB Nominal
Expected IF, center frequency input:	58.5 dBm
Required output:	- 45.0 dBm Maximum
Implied rejection:	103.5 dB

Reflected power at receiver input is approx. 29.8 dBm as follows:

Rotary Joint VSWR, Sum ch:	1.35:1.0 Max.
Antenna sum ch. VSWR:	1.5:1.0 Max.
Nominal DEA output, comm narrow beam:	46.4 dBm = 43.65 watts

Assuming nominal DEA output and a VSWR of 1.35:1.0 for the DEA to rotary joint interface, the reflected power is:

43.65 watts x 2.2% = .96 watts = 29.8 dBm.

The received signal input to the DEA, assuming -126 dBw/m^2 power density and 37.1 dBi antenna gain, is approx. -103 dBm.

Thus the expected reflected power at the DEA input is approximately 133 dB above the expected received signal level. Also, the expected reflected power into the DEA is approximately 42 dB higher than the test signal used for this test.

(g) Comm transmit freq. rejection: add a test to measure track and data IF noise level (no RF input, J4A or J5A) with transmitter ON and with transmitter OFF and verify:

(1) no change in noise level between transmitter ON and transmitter OFF conditions

(2) no change in spurious outputs between the transmitter ON and transmitter OFF conditions for the band of 647 ± 150 MHz (first IF filter band pass per DA LRU spec, Fig. 3.2.1.2-4.)

TS32012-042B - Review - Section 2 Comments (Cont'd.)

Item	Page	Paragraph
2-25	15	3.2.3.5.15 through 3.2.3.4.15.14 (Cont'd.)

(h) Main bang leakage - radar: The DA LRU spec requirement is -40 dBm; the ATP requirement is 31 mv peak. It would appear the ATP requirements are considerably less stringent than the DA LRU spec requirements.

Hughes justify/verify ATP is correct.

(i) Configuration: clarification required i.e.,--What are DA inputs associated with "mode select switch on 8", "channel 6", etc.

Item	Page	Paragraph
2-26	16	3.2.3.4.16 through 3.2.3.4.16.3

(a) Paragraph 3.2.3.4.16.3 calls for repeat of 3.2.3.4.16.1 and 3.2.3.4.16.2, but data sheets do not provide entries for a repeat of 3.2.3.4.16.1

Correct data sheet.

(b) Requirements (for measured times) are different from DA LRU spec and tolerances are considerably greater than those in DA LRU spec.

Hughes verify ATP requirements are correct--i.e., the values the system performance is based on and what EA-2 is "expecting".

Hughes provide value for "TBD", 3.2.3.4.16.1.

Item	Page	Paragraph
2-27	17	3.2.4 through 3.2.4.25

(a) Combination of text and data sheets seem to be an adequate definition of requirements for radar mode, linear polarization, channel 3 but are inadequate for other 4 frequencies and for circular polarization, Comm and radar.

Revise data sheets, and text, if required, to clarify.

IS32012-C42B Review- Section 2 Comments (Cont'd.)

Item	Page	Paragraph
2-27 (Cont'd.)		(b) Requirements for Comm (13.775 GHz, CP) and radar, active target mode (13.883 GHz, CP) are not adequately defined. Should be a maximum phase error of 30 degrees. Clarify.
2-28	Appendix A	No comments
2-29	Appendix B	No comments
2-30	Appendix C	

(a) Change requirement for comm transmit frequency (14.85 to 15.15) gain to 37.9 dBi minimum.

(DA LRU spec requirement.)

(b) Requirements for monopulse tracking scale factor for CP, beta axis is 0.5 ± 0.1; DA LRU spec requirement is 0.6 ± 0.1.

Hughes verify ATP values are acceptable--i.e., the value used in comm and radar performance analysis and the value EA-1 and EA-2 are "expecting".

(c) Add the following self test dipole measurements:

(1) Sum channel coupling, antenna circularly polarized.
(2) Difference channel coupling, alpha
(3) Difference channel coupling, beta

(d) Narrow beam beamwidth requirements are less than the DA LRU spec calls for--Comm, radar active mode tgt.

Hughes verify ATP values acceptable, i. e., the values used, or to be used for Comm and radar system performance analysis.

2-31 Appendix D--Add loss measurement for coax cable from DEA to self test dipole.

2-32 Appendix E

(a) Both High Scale (coarse) and Low Scale (fine) scale factors specified for rates of 10 degrees/second and greater.

Hughes verify no scale factor requirements for rates less than 10 degrees/second.

(b) Fine scale factor tolerance is ± 3%. C-2

Hughes verify this is acceptable.

TS32012 -042B Review - Section 2 Comments (Cont'd.)

Item	Page	Paragraph
2-33	16	Appendix F

(a) Test access connector measurements per 4.4.4.7.1 and 4.4.7.3 specify -22 ± 2 dB. This is requirement for output at J4A and J5A per MC409-0025, Para. 30.3.2.1,2.3.2.3.c. Per Hughes drawing 3561604 the cable between the DEA and J4A or J5A is appproximately 14 inches of RG142 B/U.

Add coax cables to DEA for this measurement or reduce DEA allowed coupling/loss to accommodate coax cable loss.

(b) Test access coupling measurements are made only at 15 GHz. Coupling data is also required for the frequency range from 12.48 GHz to 14 GHz.

Add measurement.

(c) Noise figure requirements per 4.4.4.8.8 (6.4 dB and 6.6 dB for sum and difference channels respectively) when the step IF AGC and Tr limiter AGC are applied are unrealistic and equipment does not comply

Revise requirements per DA LRU spec.

TS 32012-042B Review - Section 3 Comments

3. Performance requirements/parameters not verified.

Performance requirements/parameters identified in this secion are not verified by the ATP as written plus changes made to correct discrepancies identified in Sections 1 and 2 of these notes. Analysis showing that workmanship errors during fabrication and assembly, component tolerance build-ups, etc, that would result in the DA failing to perform as required, either initially or during and after exposure to the specified environments, will be detected (screened out) by inspection, inline tests or other tests performed during acceptance testing must be submitted by Hughes, and approved by Rockwell, or tests must be added to cover these items

3.1 The procedure, as written, calls for testing to be performed with nominal inputs. Review of the design and/or problems during development indicates the deployed assembly performance is, or may be, sensitive to variations allowed for certain inputs. The most critical inputs include the following:

a) Encoder Driver
b) Gyro Spin Motor Drive
c) Gyro Primary Excitation
d) 156 MHz reference
e) 1875 MHz Exciter IF
f) 28 vdc power

If tests are added to verify DA performance over the allowed range of inputs, these additional tests should be limited to measuring (verifying) selected, most sensitive, performance parameters for maximum and minimum values of the inputs and should be performed during ATVT at both temperature extremes.

3.2 Specific performance parameters not verified include the following:

a) Transmitter - Comm operations
   (1) Phase linearity
   (2) Gain Slope
   (3) AM to PM conversion
   (4) Spurious outputs
   (5) Broadband noise output
   (6) IFM
   (7) IAM
   (8) Phase noise

3.2 (Cont'd.)

b) Receiver-Comm operations

(1) Gain Slope

(2) Phase linearity

(3) AM to PM conversion

(4) Intermodulation products

c) Transmitter - radar operations

(1) Broadband noise outputs

(2) Spurious outputs

d) Receiver - radar operation --see (b) above

e) Antenna alignment - rf axes, rf axes to encoders.

f) Alignment, mirror "cube" and antenna A axis.

g) DA dynamic properties as applicable to antenna servo operations

*h) Antenna/gimbal moments of inertia (servo item)

*i) Motor torque scale factor (servo item)

j) Heater power consumption

k) Antenna gain, beamwidth, axial ratio, etc. after exposure to vibration and during exposure to a thermal vacuum environment.

*These two servo related items (h and i) can be covered by a simple transfer function test at the "cross over" frequency and at one frequency considerably less than the "cross over" frequency. Such a test would be performed in ambient laboratory environment (post environmental or final performance test) only and two or three gimbal positions should be sufficient.

APPENDIX C

ACTION ITEMS TO ADDRESS ROCKWELL COMMENTS ON

HUGHES DA ATP TS 32012-042B

HUGHES

INTERDEPARTMENTAL CORRESPONDENCE

CIP

TO: Distribution
ORG:

CC: Data Bank (2)

DATE: 28 April 1981
REF. HS237-3343

SUBJECT: RI/HAC/NASA DA ATS Comment Review Meeting

FROM: P. E. Sterba
ORG. 40-92-20
BLDG. S13 MAIL STA. D329
LOC. SC EXT. 59354

Reference: HS237-354-929 dated March 24, 1981, Subject: Purchase Order No. M7J3XMB-48139D, Ku-Band Deployed Assembly Acceptance Test Procedure with Appendices A, B, C, D, E and F (TM11-A).

Four joint Hughes/Rockwell/NASA meetings have been held to review Rockwell's comments to the DA Acceptance Test Specification (ATS) TS32012-042B contained in the above reference. Those attending these meetings are listed in table 1. Each comment was discussed and action items were defined to address the issues raised by the comments where appropriate. The defined action for each comment is given in table 2 and the corresponding notes.

A total of 123 comments were presented in the referenced document. No action is required for 14 of the comments. A summary of the disposition of these comments follow:

1) Hughes accepts comments and no action required - (5).

2) Rockwell withdrew comment - (9).

3) Hughes will change DA ATS per comment - (29).

4) Hughes action defined - (59).

5) Hughes/Rockwell action defined - (8).

6) Rockwell action defined - (13).

The subject of STE calibration is involved in 5 of the 8 Hughes/Rockwell actions and 12 of the 13 Rockwell actions.

P. E. Sterba

PES:ib

Attachment

TABLE 1: DA ATP MEETING ATTENDANCE

Attendees	MEETINGS			
Rockwell	**4/9**	**4/10**	**4/16**	**4/20**
W.S. Pope	X		X	
F.E. Cummings	X	X	X	
W.H. McQuerry	X	X	X	X
D. Potts	X	X	X	X
Hughes				
M. Meredith	X			
P.E. Sterba	X	X	X	X
K. Stern	X	X	X	X
W. Turner	X	X	X	
S. Kubo	X	X	X	
V. Karpenko	X	X	X	
T. DeGasperin	X			X
A. Hanson		X		
R. Chan	X			X
J. Riles			X	
NASA/JSC				
J. Kelley	X			
Axiomatix				
R.G. Maronde	X	X	X	

COMMENT ITEM NUMBER (REFERENCED DOCUMENT)	A ACTION KUBO REVISE ATS PER COMMENT	B ACTION KUBO (SEE NOTE)	C ACTION HUGHES (SEE NOTE)	D ACTION ROCKWELL (SEE NOTE)	E NO ACTION COMMENT WITHDRAWN BY ROCKWELL	F NO ACTION HUGHES ACCEPTS COMMENT	G NOTES
1-1	X						
1-2 a				X			N1-8a
b				X			N1-8a
c				X			N1-8a
d				X			N1-8a
1-3		X					N1-3
1-4		X					N1-4
1-5		X					N1-5
1-6	X						
1-7	X						
1-8a		X		X			N1-8a
1-8 b, c	X						
1-8d		X					N1-8d
1-8e, f, g	X						
1-9	X						
1-10						X	
1-11	X						
1-12		X					N1-12
1-13	X						
1-14	X						
1-15		X					N1-15
1-16		X					N1-16
1-17				X			N1-17
1-18	X						
1-19					X		

COMMENT ITEM NUMBER (REFERENCED DOCUMENT)	A ACTION KUBO REVISE ATS PER COMMENT	B ACTION KUBO (SEE NOTE)	C ACTION HUGHES (SEE NOTE)	D ACTION ROCKWELL (SEE NOTE)	E NO ACTION COMMENT WITHDRAWN BY ROCKWELL	F NO ACTION HUGHES ACCEPTS COMMENT	G NOTES
2-1				X			N1-8a
2-2		X					N2-2
2-3				X			N1-8a
2-4					X		
2-5		X					N2-5
2-6	X						
2-7			X				N2-7
2-8		X					N2-8
2-9a		X		X			N2-9a
b					X		
c				X			N1-8a
d			X				N2-9d
e		X					N2-9e
2-10						X	
2-11					X		
2-12		X					N2-12
2-13				X			N1-8a
2-14a	X						
b		X					N2-14b
c			X	X			N2-14c
d			X	X			N2-14d
e		X		X			N2-14e
f	X						
2-15a					X		
b		X					N2-15b
c					X		N2-15c
d				X			N1-8a
e		X					N2-15b
f		X					N2-15b
g		X					N2-15b
h		X					N2-15b
i		X					N2-15i
2-16		X					N2-12

COMMENT ITEM NUMBER (REFERENCED DOCUMENT)	A ACTION KUBO REVISE ATS PER COMMENT	B ACTION KUBO (SEE NOTE)	C ACTION HUGHES (SEE NOTE)	D ACTION ROCKWELL (SEE NOTE)	E NO ACTION COMMENT WITHDRAWN BY ROCKWELL	F NO ACTION HUGHES ACCEPTS COMMENT	G NOTES
2-17a				X			N1-8a
b		X					N2-17b
c			X				N2-7
2-18				X			N1-8a
2-19a				X			N1-8a
b				X			N1-8a
c		X					N2-19c
d		X					N2-19d
e				X			N1-8a
2-20a		X					N2-19c
b		X					N2-19d
c		X		X			N2-20c
d		X					N2-14b
2-21		X					N2-21
2-22a		X		X			N2-22a
b		X					N2-22b
c		X					N2-22c
d		X					N2-22c
e1		X					N2-22e (1)
e2		X		X			N2-22a
f	X						
g		X					N2-22d
2-23a			X				N2-14b
b		X	X				N2-23b
c	X						
2-24a					X		
b	X						
c	X						
2-25a	X						In SCN 001
b	X						In SCN 001
c	X						N2-33b
d			X				
e	X						N2-25f
f			X				
g		X					N2-25g
h			X				N2-25h
i				X			N1-8a

COMMENT ITEM NUMBER (REFERENCED DOCUMENT)	A ACTION KUBO REVISE ATS PER COMMENT	B ACTION KUBO (SEE NOTE)	C ACTION HUGHES (SEE NOTE)	D ACTION ROCKWELL (SEE NOTE)	E NO ACTION COMMENT WITHDRAWN BY ROCKWELL	F NO ACTION HUGHES ACCEPTS COMMENT	G NOTES
2-26a	X						
b			X				N2-26b
2-27a	X						
b	X						
2-28						X	
2-29						X	
2-30a	X						
b			X				N2-30b
c			X				N2-30c
d			X				N2-30d
2-31						X	
2-32a		X					
b					X		N2-32a
2-33a			X				N2-33a
b			X				N2-33b
c		X					N2-33c
3-1a			X				N3-1a
b			X				N3-1a
c			X				N3-1a
d			X				N3-1a
e			X				N3-1a
f			X				N3-1a

COMMENT ITEM NUMBER (REFERENCED DOCUMENT)	A ACTION KUBO REVISE ATS PER COMMENT	B ACTION KUBO (SEE NOTE)	C ACTION HUGHES (SEE NOTE)	D ACTION ROCKWELL (SEE NOTE)	E NO ACTION COMMENT WITHDRAWN BY ROCKWELL	F NO ACTION HUGHES ACCEPTS COMMENT	G NOTES
3-2a(1)			X				N3-2a (1)
(2)			X				N3-2a (2)
(3)			X				N3-2a (3)
(4)			X				N3-2a (3)
(5)			X				N3-2a (3)
(6)			X				N3-2a (2)
(7)			X				N3-2a (2)
(8)			X				N3-2a (2)
3-2b(1)			X				N3-2a (2)
(2)			X				N3-2a (1)
(3)			X				N3-2b (3)
(4)			X				N3-2a (3)
3-2c(1)			X				N3-2a (3)
(2)			X				N3-2a (3)
3-2d			X				N3-2a (2)
e		X					N3-2e
f		X					N3-2e
g			X				N3-2g
h			X				N3-2g
i					X		
j	X						
k			X				N3-2g

NOTES:

N 1-3. Revise DA ATS to add 'rst sentence only of the comment. The rest of paragraph will not be added to the ATS.

N 1-4. Revise DA ATS to remove second sentence in paragraph 4.2.2.1 of the ATS. Add a sentence which allows performing the thermal and vibration environmental tests in reverse order at RIA's discretion.

N 1-5. Revise inprocess test spec 32012-073 to measure phase and self test at the same time during testing of the Qualification Unit to confirm that self test is adequate to verify phase. If the results of the tests are positive, then Rockwell agrees to approve a change in the DA ATS to remove the monopulse test conducted on the slant range (approximately one week) and use the self test to verify monopulse phase.

Change figure 3-11 to agree with paragraph 4.2.2.3 in the DA ATS.

N 1-8a. Hughes - Write a short (one page or less) description of the Hughes approach to testing with special test equipment built specially for testing the deliverable equipment. Explain how Hughes has confidence that the outputs and performance of the special test equipment meet requirements without calibrating this equipment.

Rockwell - Define specific outputs from the special test equipment which Hughes is required to verify by measurement prior to acceptance testing deliverable DA hardware.

N 1-8d Revise the DA ATS to add continuous monitoring of the following signals during vibration tests:

1) The temperature sensor connected in series.

2) Both heater currents.

3) The alpha - beta lobing diode current.

4) The second IF output using a diode.

N 1-12 Review techniques for measuring leak rate at ambient or during thermal vacuum test to see if test can be added to verify leak requirement.

N 1-15 Revise DA ATS per comment except temperature may be recorded every 30 minutes (instead of every 15 minutes) during ATVT.

N 1-16 Revise DA ATS to list what inputs and outputs are to be monitored during ATVT.

N 1-17 Determine acceptability of allowing spikes which exceed the random vibration tolerances listed in this comment during random vibration testing.

N 2-2 Revise DA ATS to add procedure for redeploying the antenna prior to conducting the drift tests and define the configuration (state) of the hardware.

N 2-5 Revise DA ATS to define hardware configuration during tests described in paragraph 3.2.3.3.3.1 of the ATS.

N 2-7 Turner: Comply with comment by documenting required analysis in Development Test Report TM 012.

N 2-8 Revise DA ATS to retain main scan and deleate miniscan per comment.

N 2-9a Hughes: Revise ATS to add operational steps to clarify procedure including configuration information.

Rockwell: N1-8a

N 2-9d Riles: Review paragraph 3.2.3.3.7.2 of DA ATS and explain test point scale factor value.

N 2-9e Revise DA ATS to add words "stop to stop" to paragraph 3.2.3.3.7.2.

N 2-12 Revise DA ATS to add power consumption limit values. Ron Chan is to provide these values to Kubo (for ATS) and System Engineering for update of SE08A.

N 2-14b Revise DA ATS to add requirement for change in peak power output between measurements with a common test setup (same cable effects) to repeat within 1.5 $\pm$ db.

System Engineering Mohler: Review test approach and determine if measurement error can be reduced to value consistant with hardware performance requirement.

N 2-14c Hughes - Stern: Change DA Development Specification to increase peak power tolerances to $\pm$ 3db.

N 2-14d Hughes - Stern: Determine correct value for power output in the TWT by-pass mode and write ECR to correct Development Specification and ATS.

Rockwell: Revise MC409-0025 to reflect the value established by System Engineering.

N 2-14e Hughes: Revise DA ATS to add acceptance criteria for power monitor output at high power.

Rockwell: Determine acceptability of two point calibration of monitor output

Suggested calibration technique: Feed Ku-Band variable power source into waveguide ahead of rotary joint and calibrate power monitor.

N -15b Revise DA ATS data sheet page 70 (3.2.3.4.6) to clarify operation.

N 2-15c Information: Equipment mode is COMM A ON.

N 2-15i Add additional entry to data sheet.

N 2-17b Revise DA ATS to add measurement of time from exciter gate trailing edge to RF pulse trailing edge.

N 2-19c Revise DA ATS to define range of sweep to the 3db points.

N 2-19d Revise DA ATS to add bandpass value.

N 2-20c Hughes: Revise DA ATS to add power monitor acceptance limits to data sheet.

Rockwell: N 1-8a

N 2-21 Revise DA ATS to add acceptance levels for items listed in comments.

N 2-22a Hughes - Revise DA ATS to define the hardware configuration during the track IF test.

Rockwell - N1-8a

N 2-22b Revise DA ATS that the bandwidth is defined as the 3db point.

N 2-22c Revise DA ATS to deleate the ripple requirement.

N 2-22d Revise DA ATS data sheet to require photographs be taken

N2-22e(1) Review comment with Hughes RF specialists and develop a response to the comment.

N 2-23b Kubo: Determine the feasability of measuring % AM per degree during initial phase adjustment on the slant range.

ORIGINAL PAGE IS OF POOR QUALITY

System Engineering: Define % AM requirements.

Note: Rockwell - McQuerry states that rotary joint test requirement can be deleted if % AM test is added.

N 2-25f Receiver COMM frequency rejection measurement contained in DA ATS has been corrected by SCN 001.

Kubo: ~~Revise DA ATS to add test to measure trans[illegible]~~ isolation requirement specified in DA Development Specification.

N 2-25f (cont'd)

System Engineering - Stern: Review DA Development Specification and add transmitter isolation requirement if it is not specified (reference MC409-0025, par. 3.0.3.2.1.2.3.7q).

N 2-25g Revise DA ATS to satisfy comment

(1) and (2) respectively by the following action:

(1) Satisfy by photographs of spectrum analyzer output when measuring data and track IF.

(2) Accomplish by visual observation for an interval greater than 30 seconds.

N 2-25h System Engineering - Stern: Review ATS measurement value per comment and confirm ATS value is correct.

N 2-26b Kubo: Document how the tolerance for receiver gate to detected Radar IF measurement was determined.

Turner/Karpenko: Determine how performance requirements are going to be verified if test accuracy is insufficient to verify requirements to specified tolerance.

N 2-30b Turner/Karpenko: Submit an ECR to change the monopulse scale factor in the DA Development Specification from 0.6 ± 1 to 0.5 ± 0.1 which agrees with achievable DA antenna performance.

N 2-30c Hanson: Revise DA ATS Appendix C to add measurements requested by comment with note that they are for information only.

N 2-30d Turner/Karpenko: Submit ECR to DA Development Specification to change the narrow beam beamwidth to agree with the ATS.

N 2-32a Revise DA ATS Appendix E, paragraph 4.1.5.c by replacing the words "rates higher" with "rates lower".

N 2-33a DeGasperin: Revise the DEA ATS to comply with comment.

N 2-33b Previously requested coupler test data down to 12.48 GHz was provided by DeGasperin and accepted by McQuerry.

DeGasperin: Submit an ECR to Appendix F of the DA ATS to add measurement of coupling value for both couplers in the Radar Band (already measured in COMM transmit band).

N 2-33b (cont'd)

DeGasperin: Generate analysis to define expected out of band (12.48 to 15.3 GHz) coupling value performance.

Turner/Karpenko: Document above DA analysis in Development Test Report TM 012.

N 2-33c Prepare an SCN to delete noise figure measurement for transmitter AGC per ECR 936524.

N 3-1a Turner: Collect existing development test data for inputs listed in comment and provide to Rockwell by April 30, 1981.

N3-2a(1) DeGasperin: Define justification for not measuring parameters during DEA acceptance testing (AT).

Turner: Define justification for not measuring parameters during DA AT. Document the DA and the DEA justification in Development Test Report TM 012.

N3-2a(2) System Engineering - Mohler: Define and document justification for not measuring parameter during AT.

N3-2a(3) DeGasperin: Define justification for not measuring parameter during DA AT.

Turner/Karpenko: Document above justification in Development Test Report TM 012.

N3-2b(3) System Engineering: N3-2a(2)

System Engineering: Define performance of parameters and add to DA Development Specification.

N3-2e Document technique of aligning RF antenna axis to the reference mirror "cube".

N3-2g Turner/Karpenko: Determine parameter performance by analysis and document in Development Test Report TM012.